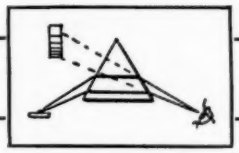
Journal of the OPTICAL SOCIETY *of* AMERICA

VOLUME 23
No. 4



APRIL
1933

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Published monthly
at Prince and Lemon Sts., Lancaster, Pa.
by the
AMERICAN INSTITUTE OF PHYSICS
Incorporated
11 East 38th Street, New York, N. Y.
FOR AND UNDER THE EDITORIAL SUPERVISION OF
THE OPTICAL SOCIETY OF AMERICA

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Journal of the
OPTICAL SOCIETY *of* AMERICA

VOLUME 23 APRIL, 1933 NUMBER 4

A Method of Measuring Axial Chromatic Aberration in an Objective Lens

W. HERRIOTT, *Bell Telephone Laboratories, New York*
(Received February 7, 1933)

NO commercially available photographic lens offers perfect definition over an extended field because of the influence of inherent aberrations. The aberrations are usually so distributed as to result in the best possible average definition over the required picture area. In general, such a lens is of high relative aperture and is intended for use with an object distance that is many times its focal length. Commercial considerations have, in certain cases, led to the development of special types of lens systems where the lens designer has been able to meet requirements imposed by special needs. The process lens is illustrative of this type. In this case, corrections are effected at a low relative aperture for a magnification of approximately unity and particular care is given to the correction of lateral chromatism as this aberration would obviously prohibit precise registry of negatives made through trichromatic filters.

Many physical instruments are now in use in which photographic methods are employed to record a wide variety of transient phenomena. The modern high-speed oscillograph is representative of this type of instrument and such instruments, in general, employ a lens system as a means of imaging an aperture onto the plane occupied by the light sensitive material. Such imagery may be effected under a wide variety of conditions for which certain optical factors may not receive proper design consideration. Such factors involve the brightness and energy distribution of the light source, the magnification adopted, and particularly the extent of angular field required. Factors relating to photographic materials such as resolving power, spectral sensitivity, contrast and speed are of equal importance. We frequently observe instances where commercially available lenses have been applied to these uses under conditions widely different from those for which such lenses were originally designed.

As suggested above, particular use considerations may justify the design of special lens systems in which improved optical efficiency may be secured by giving close attention to the influence of the various factors which determine the performance of the instrument. In some cases, sharp definition may be required only over a limited field and under conditions where a lens of low relative aperture can be employed. In case a photographic material of low speed is used, it may be necessary to increase relative aperture to a point where definition will be effected.

At Bell Telephone Laboratories we have given consideration to a choice of a lens system which is required to work with a low-speed emulsion under illumination conditions which necessitate the use of the high relative aperture of $f : 1.5$. It is also necessary that this lens shall give the best possible definition over a limited angular

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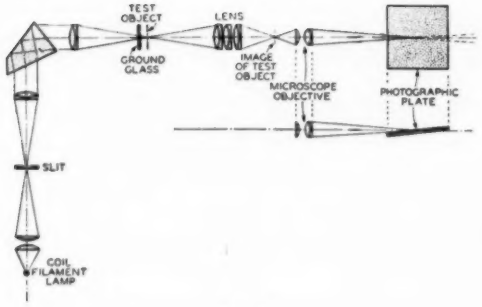

FIG. 1.

field of approximately 3.5 degrees. The object consists of a small illuminated rectangular aperture which is imaged at the film plane at a magnification of approximately 0.5. The particular lens which we had been using for this purpose served well until it became desirable to increase the sharpness of the image. Lens bench examination of the image structure indicated the presence of axial chromatic aberration.

A photographic method of measuring axial chromatic aberration has been applied to a study of this and similar lenses. The method involves the projection of an image formed by the lens under test onto a steeply inclined photographic plate.

Fig. 1 shows schematically the apparatus used. The slit of a constant deviation spectrometer is illuminated by a small coil filament tungsten lamp and condenser. These units are adjusted to form an out-of-focus image of the closely spaced coil filament at the slit. The eyepiece of the spectrometer has been removed and a test object consisting of five transparent lines of 0.001 inch width and 0.250 inch length, separated by opaque lines of the same dimensions, is placed at the approximate focus of the telescope objective. Immediately behind this test object is located a small piece of finely ground glass which serves to permit filling of the aperture of the lens under test, which is shown to the right of the test object. The lens under test forms an image of the test object at a magnification of 0.5. The total width of the test object is limited to a value of 0.010 inch in order that a reasonably pure monochromatic radiation will be transmitted to the lens. A 16 millimeter Bausch and Lomb apochromatic microscope objective serves to relay the image of the test object formed by the lens under test onto a steeply inclined photographic plate at a magnification of 10.0. The image formed by the microscope lens lies, of course, in a plane perpendicular to the optical axis and the inclined photographic plate records a trace of the focal region surrounding a focal point. The position of the constant deviation prism in the spectrometer can be altered and a reading of the wave-length scale indicates the wave-length of the radiation incident upon the test object. Assume that a wave-length of 4000A is illuminating the test object, the lens under test will form an image of the test object which will lie at some distance in advance of the first principal focal point of the microscope objective. The image formed by the microscope objective will lie at a definite distance to the rear of its second principal focal point. If an axial movement of the image of the test object formed by the lens under test occurs, it is obvious that a shift of the image formed by the microscope objective will also occur. The longitudinal change in position of the image which intersects the photographic plate will correspond to a longitudinal shift of the image of the test object which has been formed by the lens under test. This change in x' is proportional to the square of the magnification of the microscope objective for the wave-length concerned.

A series of exposures is made on a single plate. These exposures differ only in respect to the wave-length of light incident upon the test object. If the color curve is not flat, the images of the test object formed by the lens under test will occupy different image planes. This shift of image plane with wave-length will be indicated

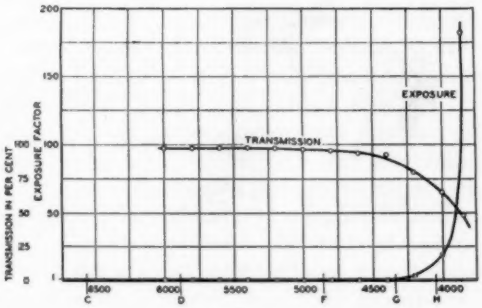

FIG. 2.

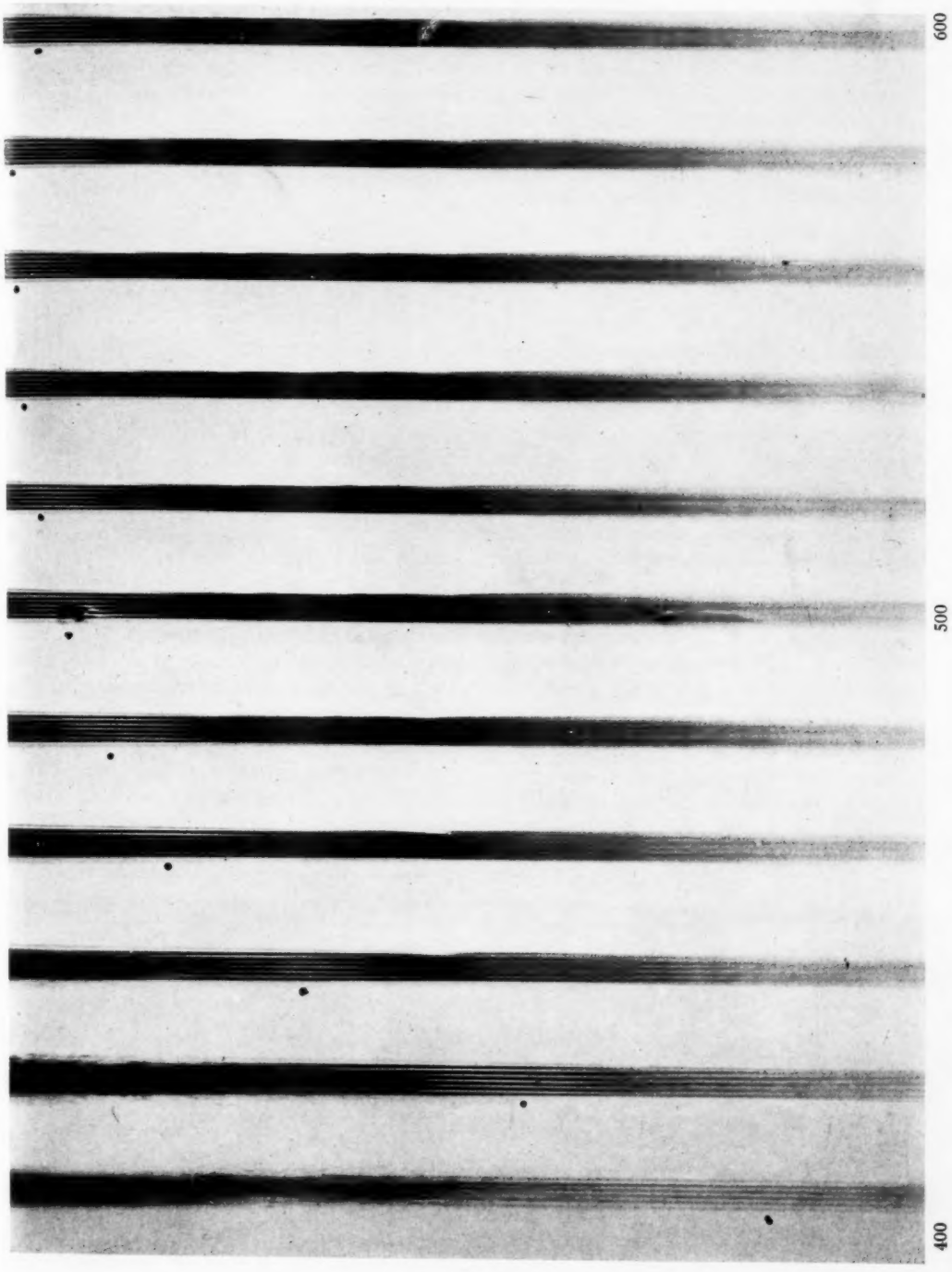

FIG. 3.

on the inclined photographic plate as a change in position of the point of sharpest definition. This change in position will, of course, be a function of the wave-length of light used and is directly dependent upon the nature of the axial chromatism of the lens under test. In this manner we can trace a curve connecting the series of points on the inclined photograph which represents on a greatly enlarged scale the values of axial chromatic aberration of the lens under test.

The dense flint prism used in the spectrometer exercises a high absorption in the ultraviolet region. Fig. 2 shows the transmission characteristic of this prism and also shows a correction factor which is applied to exposures in order to compensate for this loss.

Fig. 3 has been made in the above-described manner and shows a change in the point of sharpest definition as a function of wave-length. The inkmarks serve only roughly to locate the various points of sharpest definition.

Fig. 4 shows a comparison between computed values of axial chromatic aberration and values derived by three methods of measurement. A curve is shown which represents a visual examination of the lens in which a ten power eyepiece was used with the 16 mm apochromat micro-objective in the normal way. A direct reading micrometer gauge was attached to the microscope and focal settings made on the image of the test target visually, and differences noted. A curve is also shown which is designated "focus plates." This curve resulted from an

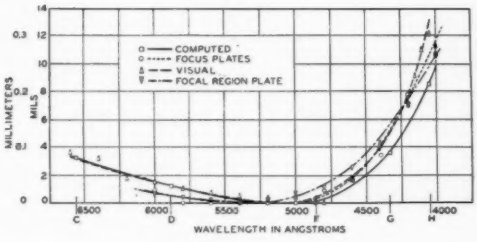

FIG. 4.

examination of an extended series of photographs of the image of the test object secured with the 16 mm microscope objective where the photographic plates were placed normal to the optical axis of the objective. The microscope and plate were moved longitudinally through an extended range and many exposures made at definite settings for each selected wave-length. This

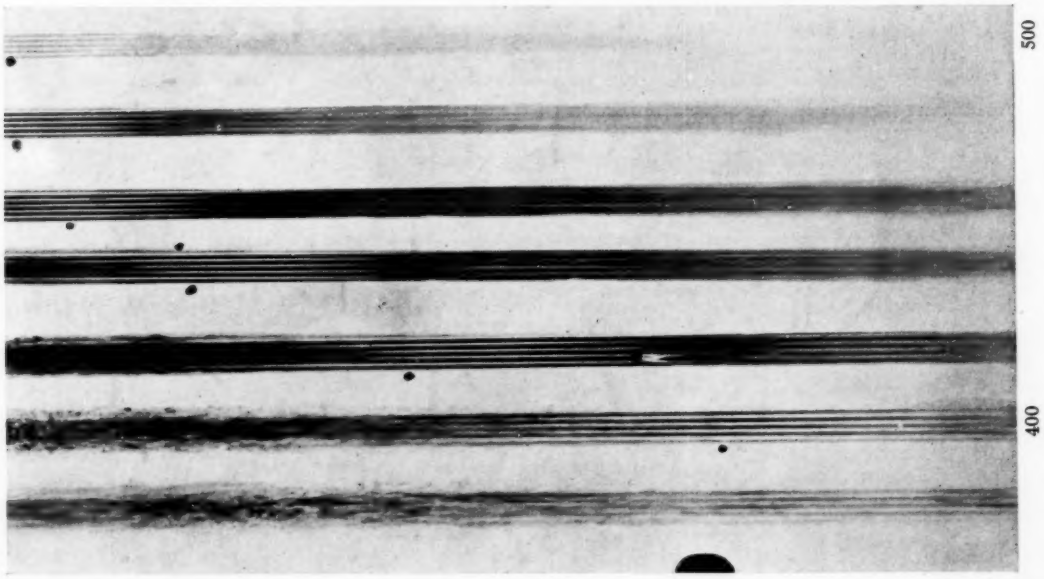

FIG. 5.

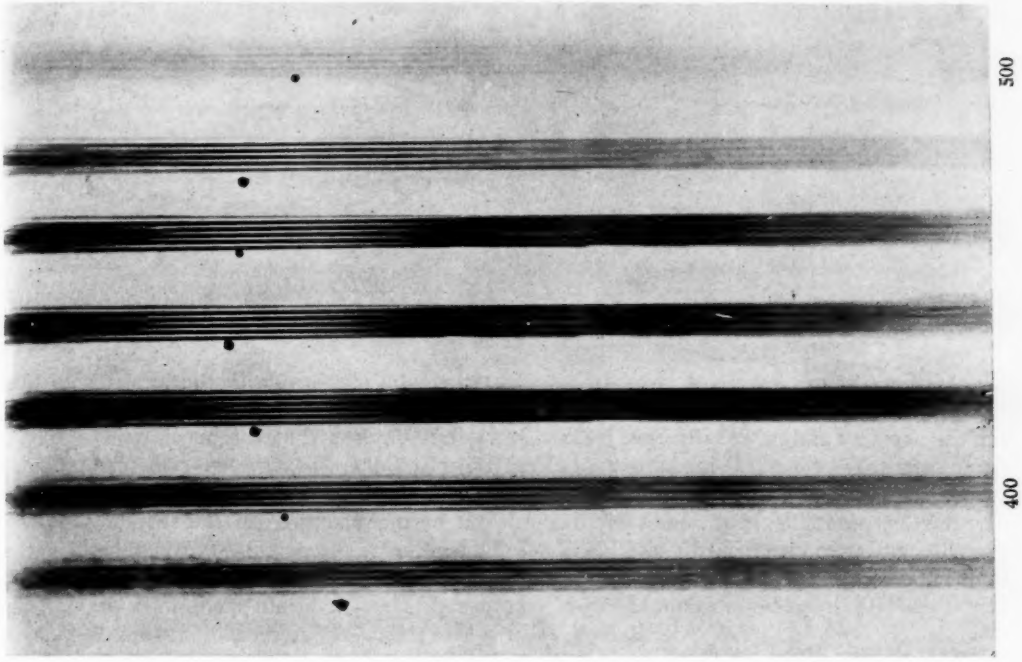

FIG. 6.

process was repeated at all desired wave-lengths and a visual examination of the plates indicated the location of the plane of sharpest definition and a curve was readily plotted which shows these results in graphical form. The fourth curve shows a curve derived from the focal region plate shown on the preceding figure. An average curve would result in a departure of less than 0.001 inch between computed and all observed values. The particular lens used for these tests has an equivalent focal length of 1.500 inch.

The photographic emulsion with which this lens is used is sensitive only to the blue and violet and Fig. 5 shows a focal region plate made on a process type of emulsion for which a constant exposure has been given at all wave-lengths. It is obvious that the greatest photographic effect occurs at 4200A, 4400A and 4600A with a lesser effect at other wave-lengths shown. This figure shows clearly the unfavorable state of axial chromatic correction which exists in this lens over the portion of the spectrum to which this material is sensitive.

Consideration of these results by the lens designer has led to the design of a new lens for which a much more favorable condition is attained as shown by Fig. 6. Fig. 7 shows this correction plotted to the same scale used on Fig. 4. The departure from a flat characteristic is of the order of 0.001 inch at 4000A and 5000A.

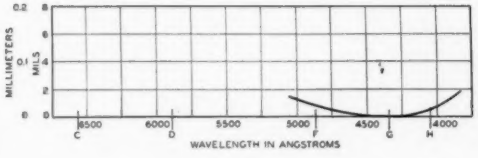

FIG. 7.

At intermediate values where the radiation is most effective in building up density we note that the curve is essentially flat. Fig. 8 represents focal region exposures for both of the above-mentioned lenses made in a similar manner excepting that the spectrometer was removed and the tungsten light source focussed directly on the test object. A difference in the quality

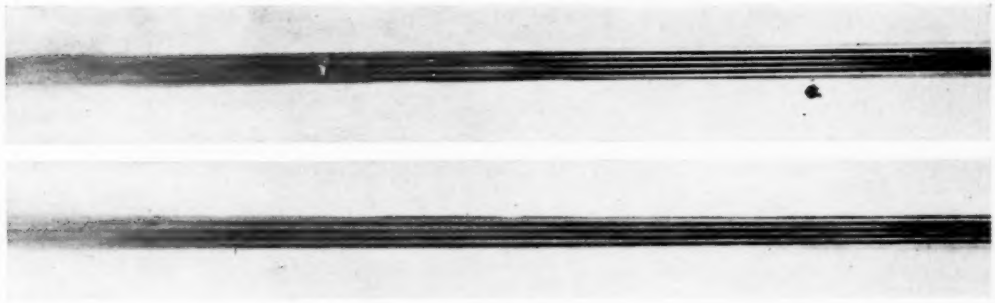

FIG. 8.

of definition offered by these two lenses is readily shown. Contrast is decidedly improved with the new lens and other tests have indicated a very definite improvement in sharpness of the image. Fig. 9 shows values of axial chromatic aberration for the 16 mm apochromat microscope objective as determined visually at Bell Telephone Laboratories and also shows corresponding values derived by computation. I wish to acknowledge the courtesy of the Bausch and Lomb Optical Company in making these data available to us. These values were obtained in order to determine the possible influence of the characteristics of the microscope objective on the results obtained with the focal region plate method.

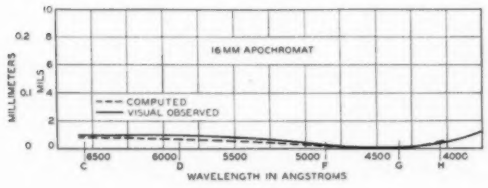

FIG. 9.

It is obvious that the apochromatic type of objective offers a very flat color characteristic over an extended wave-length range. Such lenses can be manufactured in the smaller sizes with a high relative aperture and can be corrected for the desired magnification. The increasing use of this type of objective might be expected where critical definition is required over a narrow field. The limit in the size, focal length and aperture which can be secured in the apochromat construction appears to be established by the availability of suitable material for its construction.

Consideration is being given to the possible application of the above-described method of test to the measurement of spherical aberration in lenses. The use of a single rectangular aperture at the test object together with a series of apertures immediately in front of the lens under test may serve to make possible the accurate determination of crossing distances for the various zones of the lens.

The Luminescence of Alkaline Earth Tungstates Containing Lead

FRANK E. SWINDELLS, *The Patterson Screen Company, Towanda, Pennsylvania*

(Received January 20, 1933)

Lead is shown to be an activator for the phosphorescence of calcium and strontium tungstates, the optimum concentration being about 0.01 mol of $PbWO_4$ per mol of alkaline earth tungstate. In addition, it was observed that much higher concentrations of lead produce an enormous increase in both the fluorescent and phosphorescent power of strontium tungstate. The optimum concentrations of lead for this effect are 0.2 and 0.4 mol fraction for the fluorescence and phosphorescence, respectively. High concentrations of lead in calcium tungstate serve only to decrease the luminescent power.

AT the present state of our knowledge luminescent solids appear to be of two types: those in which the luminescence is a property of the pure compound; and those in which the luminescence is to be attributed to the presence of an impurity known as an activator.

The tungstates and molybdates of the alkaline-earth metals, and also magnesium, zinc and cadmium, have been known for a long time to be capable of luminescence with proper excitation. No known activator is to be associated with this luminescence, and these substances appear to belong to the first group above. On the other hand, it has been generally recognized that the phosphorescence, or the small portion of the luminescence which persists after excitation has ceased, particularly that of calcium tungstate, is due to the presence of impurities. With the exception of certain of the rare-earth metals,[1] very few activators have been identified. Tiede and Schleede[2] attributed the afterglow to traces of sodium salts and in a later paper[3] Schleede and Tien-Huan Tsao identified arsenic and antimony as activators.

During the examination of a large number of samples of luminescent calcium tungstate, one sample was found with an intense and persistent afterglow. The duration and rate of decay of this substance have been published.[4] A spectrographic analysis showed this sample to contain a trace of lead. Samples of calcium tungstate containing various amounts of lead were synthesized, and an examination showed that lead was the activator.

The most effective method of introducing the lead was found to be by the addition of a boiling solution containing lead and calcium ions in the desired ratio to a boiling solution of an excess of sodium tungstate. The precipitate was filtered, washed and dried. Sodium chloride weighing about 15 percent of the weight of the mixed tungstate was mixed in and the whole ignited in a chemical porcelain crucible at 1000°C for 15 minutes and removed from the furnace immediately. After dissolving out the sodium chloride, the tungstate remained as a fine microcrystalline powder. In this manner a series of a calcium-, strontium- and barium-lead mixed tungstates was prepared, in which the lead concentration was varied through wide limits. The chemicals used were of the usual c.p. quality, and the sodium tungstate and calcium chloride were specially selected from a large number of lots for their ability to produce calcium tungstate with a minimum of phosphorescence when no activator was added.

The luminescent intensities during and following excitation by x-rays were compared by a photographic method. A piece of Bakelite $5\times7\times\frac{1}{8}''$ had fifteen $\frac{1}{2}''$ holes drilled in it. A

[1] de Rohden, Ann. de Chimie **3**, 338 (1915).

[2] E. Tiede and A. Schleede, Zeits. f. Electrochemie **29**, 304 (1923).

[3] A. Schleede and Tien-Huan Tsao, Berichte **62B**, 763 (1929).

[4] F. E. Swindells, J. Opt. Soc. Am. and R. S. I. **16**. 165 (1928).

piece of thin transparent celluloid was cemented to one side of the Bakelite with dilute collodion. The various samples to be tested were then pressed in the cells thus formed. To compare the fluorescence intensities, a 5×7″ x-ray film was placed in the bottom of an empty cassette and the Bakelite plate on top with the celluloid side in contact with the film. An exposure to x-rays was then given with the x-rays entering the cassette from the side containing the film. After the usual development, the densities produced on the film by the various samples and also the background density were measured by a Martens-Maximovitch densitometer. The horizontal line in the figures showing fluorescence marked "x-ray density" represents the density produced on the background by the photographic action of the x-rays. The fluorescent light from the various samples produce an additional exposure on the portion of the film in contact with them, and this increased blackness is thus a measure of their relative fluorescent power.

In a similar manner the energies of phosphorescence during a definite period of the decay were compared for the various samples. In this case the plate containing the samples was given an exposure to x-rays (the exposure being many times greater than that required to test the fluorescent power) and after a definite interval brought in contact with a film. After a suitable time in contact with the phosphorescing samples, the film was removed and given the usual development. The blackness of the images obtained on the film is a measure of the energy emitted as phosphorescence during the time the substances were in contact with the film. The fog density or density of the unexposed background is represented by a horizontal line in the figures.

The source of the x-rays was a 30 m.a. Coolidge tube energized by a mechanically rectified x-ray machine.

In Figs. 1 and 2 are shown the results obtained with calcium tungstate containing the indicated mol fractions of lead tungstate. The concentrations are plotted as square roots in order to give better distribution of the lower concentrations. The ability of lead to serve as an activator for the phosphorescence of calcium tungstate is established by Fig. 2. The optimum concentration, or concentration of lead which produces the maximum phosphorescent power, is 0.01 mol fraction $PbWO_4$. The possibility that the activation is caused by some impurity in the lead salts used is not eliminated. The fact that the optimum concentration of lead is higher than optima usually found for activators might appear to lend weight to this possibility. Actually two samples of c.p. lead chloride and one sample of c.p. lead nitrate gave the same optimum within the experimental error. Thus the impurity

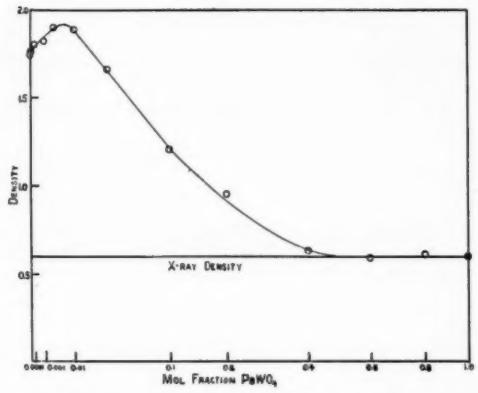

FIG. 1. Fluorescence of calcium tungstate-lead tungstate mixtures; exposure 60 kv, 2 m.a., 2.0 secs., 1 meter distance.

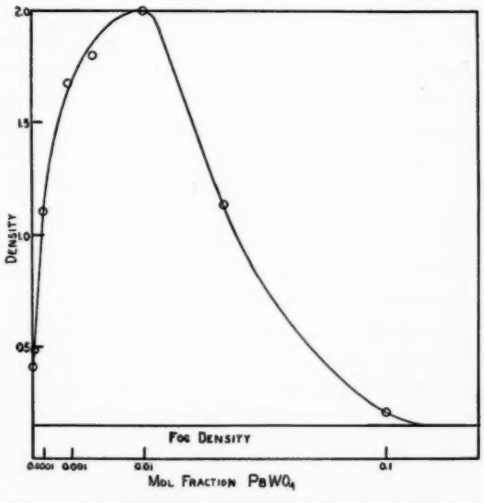

FIG. 2. Phosphorescence of calcium tungstate-lead tungstate mixtures; exposure 60 kv, 2 m.a., 10 sec., 30 cm distance; after 15 second interval placed in contact with film for 5 minutes.

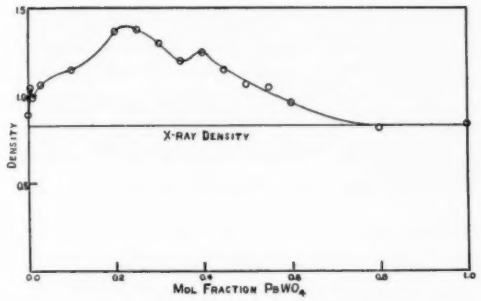

FIG. 3. Fluorescence of strontium tungstate-lead tungstate mixtures; exposure 60 kv, 2 m.a., 3.5 sec., 1 meter distance.

would have to be present in all three samples in about the same concentration which is rather unlikely.

In Fig. 1 the small rise in the fluorescence intensity at the optimum concentration of lead to produce phosphorescence was repeatedly confirmed and is probably due to the superposition of the phosphorescence process on the fluorescence process.

Similar series of preparations of strontium tungstate containing lead were made by the same method. Since the luminescent power of strontium tungstate is much less than that of calcium tungstate, much longer exposures were required to obtain the effects with these salts.

In Fig. 3 the density produced by the fluorescence is plotted against the concentration of lead. The surprising fact is noted that, in addition to the maximum at 0.01 mol lead similar to that noted for calcium tungstate, a tremendous increase in intensity is obtained through a wide range of concentrations of lead with a fairly well defined maximum at 0.23 mol fraction of lead. A secondary maximum is indicated at 0.4 mol lead, but this is not outside the possible limit of experimental error and should not be considered as established. It should be noted that even the optimum mixture has considerably less fluorescent power than pure calcium tungstate.

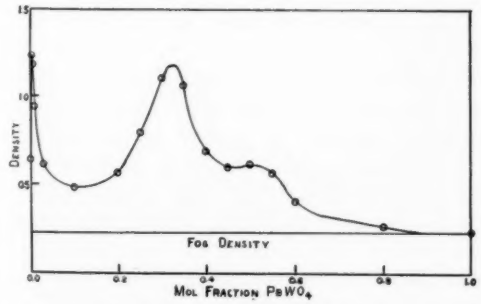

FIG. 4. Phosphorescence of strontium tungstate-lead tungstate mixtures; exposure 60 kv, 2 m.a., 75 sec., 30 cm distance; after 15 second interval placed in contact with film for 5 minutes.

The same type of increase in phosphorescence occurs as shown in Fig. 4 although the maximum intensity appears at a higher concentration of lead. Again there is some indication of a secondary maximum, but as in the fluorescence results it may be due to errors of measurement.

A series of barium tungstate-lead tungstate mixtures were also made, but the luminescence was so feeble that accurate measurements were impossible. It was established, however, that mixtures of the two salts prepared as described show considerably more fluorescence than either salt alone.

As a rough check the whole series of preparations contained in thin glass vials were placed in a lead box with a lead-glass window and an opening for the entrance of x-rays. The intensities were compared visually both for fluorescence and phosphorescence and the preparations arranged in the order of intensity as closely as they could be judged. This order was identical with that determined photographically. It was of interest that the fluorescence of pure lead tungstate could just be detected by the well-accommodated eye, but the intensity was not sufficient to appear photographically in the above tests.

A satisfactory explanation of the effects obtained at the higher concentrations of lead in strontium (and barium) tungstate cannot be offered at this time. The most likely hypothesis would seem to be the formation of a compound between the lead tungstate and strontium tungstate which has a greater luminescent power than either of its components; or if mixed crystals are obtained optimum atomic spacings may be reached in the mixed crystal. A crystallographic analysis of the preparations might throw some light on these points. The fact remains unexplained that the maximum fluorescent effect

is at a different concentration from that of the maximum phosphorescent effect, unless it is assumed that the processes are so different that different compounds or crystal dimensions are required for the two effects.

It might also be thought that the effects are due to a shift in the position of the bands of the luminescent spectrum. Considering the rather wide spectral range of photographic sensitivity together with the agreement with visual observation of the intensities, rather enormous shifts would be required. Such shifts as have been noted in other systems as the base is progressively changed have been quite small.

Intensity and Spectral Distribution of Solar Radiation in New Orleans

HENRY LAURENS AND H. S. MAYERSON, *Laboratory of Physiology, School of Medicine, Tulane University of Louisiana*

(Received November 18, 1932)

THE increasing popularity of heliotherapy has made it desirable that physiologists and clinicians, as well as physicists and meteorologists, should have some knowledge of solar radiation. We are now in possession of many facts pertaining to the effects of radiant energy, but we still need more information concerning the character of the radiation used. The intensity of solar radiation varies considerably on the earth's surface, chiefly on account of geographic position, the season of the year and the time of the day. The amount of radiation which reaches the earth's surface is also dependent upon every momentary change in atmospheric transparency, cloudiness, dustiness, humidity, and so forth. A rigorous comparison of the results obtained with solar radiation by different investigators at different times and places is practically impossible.

New Orleans is a semi-tropical, sea-level city. Its temperature is mild throughout the year, the average daily temperature for the last 57 years being 69.4°F. The average percent of possible sunshine is 58 percent (average of 40 years), an amount similar to that obtained in Boston, New York City, Chicago and Minneapolis. This seemingly low percentage of sunshine is due to the great number of cloudy and rainy days, especially during the summer months, there being only an average of 7 clear days in July as compared with 11 in March and 16 in October (average of 60 years). The relative humidity is high, averaging 83 percent at 7 A.M. (average of 42 years), 63 percent at noon (average of 13 years), and 72 percent at 7 P.M. (average of 42 years). The monthly mean water vapor pressure rises from 8.08 mm in January to 20.83 mm in July, as compared with 3.49 and 16.33 mm for the same months in Washington, D. C.[1] The average annual precipitation is 59.39 inches (average of 60 years), an amount considerably higher than in many other parts of the country.

In connection with studies on the seasonal variation in the effectiveness of sunshine in preventing rickets in rats and chicks,[2, 3, 4] we have, since January, 1928, measured the total intensity and distribution of solar radiation in New Orleans. The measurements for the four years, 1928 through 1931, were made from a tower about 40 feet above sea level built on the roof of a small building adjacent to the laboratory. Since January, 1932, the measurements have been made from a better location on the roof of the laboratory building about 100 feet above sea level. This building is situated on the college campus about 4 miles away from the business center at a latitude of 29° 56′ N, and longitude of 90° 7′ 19″. The atmosphere is reasonably clear of smoke and dust. Direct solar radiation at normal incidence was measured with the pyrheliometer described by Gorczynski,[5] a large Moll surface thermopile and a registering millivoltmeter. The pyrheliometer (thermopile and millivoltmeter) is calibrated by exposing it to a known amount of energy and the readings expressed in terms of gram calories per square centimeter per minute. In the later part of the study, solar radiation on a horizontal plane was measured with a Kimball and Hobbs[6] pyrheliometer as modified by the Eppley Laboratory. By shielding the thermopile from the direct sun, records of the diffuse radiation from the hemispherical dome of the sky are obtained. This

[1] H. H. Kimball, Monthly Weather Review **47**, 769 (1919).

[2] H. Laurens and H. S. Mayerson, Am. J. Dis. Child. **45**, 66 (1933).

[3] H. S. Mayerson and H. Laurens, Poultry Science **11**, 325 (1932).

[4] H. S. Mayerson and H. Laurens, Am. J. Physiol. **102**, 422 (1932).

[5] L. Gorczynski, J. Opt. Soc. Am. **9**, 455 (1924).

[6] H. H. Kimball and H. E. Hobbs, J. Opt. Soc. Am. **7**, 707 (1923).

pyrheliometer was calibrated, through the kindness of Dr. Kimball of the U. S. Weather Bureau, Washington, against a Marvin pyrheliometer which had been compared with the standard Smithsonian pyrheliometer, and the readings are likewise expressed in gram calories per square centimeter per minute.

The distribution of energy in direct solar radiation at normal incidence was determined by interposing appropriate screens (1 cm quartz water cell, Corning Noviol O and Corning G 24) in front of the Gorczynski pyrheliometer and calculating the ultraviolet, luminous and infrared radiation by the method of difference. The cut-offs of these screens were determined by us with a Hilger quartz spectrograph (E 4) and their transmission curves with Hilger ultraviolet, visible and infrared monochromatic illuminators. Our quartz water cell absorbs all radiation longer than 1.4μ, and transmits about 80 percent of the rest of the spectrum, Noviol O cuts off at $372m\mu$, transmits less than 5 percent of the wave-lengths shorter than $400m\mu$ and 76 percent of the luminous and near infrared radiation, while G 24 absorbs all wave-lengths shorter than $620m\mu$ and transmits 73 percent of wave-lengths from $620m\mu$ to 1.4μ. Since the amount of ultraviolet transmitted by Noviol O is so small, we have considered the screen as absorbing practically all radiation shorter than $400m\mu$, the commonly accepted upper limit of the ultraviolet. By using (1) the water cell alone, (2) the water cell and Noviol O, (3) the water cell and G 24, readings are obtained which, after suitable correction for reflection and absorption, indicate the amount of energy of wave-lengths longer than 1.4μ; of wave-lengths shorter than $400m\mu$; and of wave-lengths between 400 and $620m\mu$, and between $620m\mu$ and 1.4μ. We have also measured the antirachitic solar energy, that is, the ultraviolet shorter than $313m\mu$, by the exclusion method as described by Coblentz and Stair,[7, 8] using a Corex purple filter, G 986 A, the quartz water cell, and window glass.[9] The G 986 A filter transmits about 78 percent of the wave-lengths between 300 and $375m\mu$ cutting off at 248 and $440m\mu$. The window glass used has a transmission of about 0.5 percent at $313m\mu$, 49 to 50 percent at $334m\mu$, 85 percent at $365m\mu$ and 88 to 90 percent in the luminous and near infrared. The long wave limit of the ultraviolet cut-off is taken at (and including) $313m\mu$ (instead of 310, the absolute cut-off) because it is a definite and easily obtained emission line (of the mercury spectrum) and, also, because antirachitic action terminates practically at this wave-length. The necessary corrections to the data have been applied according to the suggestions of Coblentz and Stair, particularly in regard to the reduction factors used in evaluating the wave-lengths longer than $313m\mu$ included in the measurement of those shorter than this. In order to obtain greater sensitivity in the measurement of small amounts of energy, especially in the ultraviolet, the millivoltmeter was supplemented by a high sensitivity D'Arsonval galvanometer (Leeds and Northrup, with a current sensitivity $= 1$ mm $= 2.4 \times 10^{-11}$ amp.).

The distribution of the energy from the sun and sky and from the sky only as received on the horizontal surface of the Eppley pyrheliometer was determined in a similar manner by the use of large filters ($6\frac{1}{4} \times 6\frac{1}{4}$ in.) except that a Corning glass filter, G 392 H, was used in place of the water cell to absorb the red and infrared radiation. This screen absorbs all of the ultraviolet below $343m\mu$ and transmits about 55 percent of the energy from 400 to $620m\mu$ and about 7 percent of the infrared. For the sake of uniformity the cut-offs have been taken as being at 400 and $620m\mu$ and suitable corrections applied for the small amounts of ultraviolet and infrared transmitted.

Solar Radiation Intensities at Normal Incidence

The amount of solar radiation present at noon on cloudless days in New Orleans is usually well above one g cal. per sq. cm per min. throughout the year. Table I shows the average intensities at 10 A.M., at noon, and at 2 P.M., as well as the absolute maxima, for the months of the year.

[7] W. W. Coblentz and R. Stair, Bur. Standards J. Research **6**, 951 (1931).

[8] W. W. Coblentz, R. Stair and J. M. Hogue, Bur. Standards J. Research **7**, 723 (1931).

[9] We are indebted to Dr. W. W. Coblentz of the Bureau of Standards for the loan of two barium glass filters used in the later part of this study.

TABLE I. *Solar radiation intensities at normal incidence. Composite average, January, 1928, through August, 1932 (g cal./sq. cm/minute).*

	No. of observations	10:00 A.M.	Noon	2:00 P.M.	Absolute maximum
Jan.	17	1.046	1.151	0.980	1.360
Feb.	20	1.019	1.186	0.972	1.392
Mar.	18	1.176	1.305	1.166	1.450
Apr.	20	1.172	1.196	1.108	1.349
May	28	1.158	1.201	1.048	1.344
June	22	1.177	1.212	1.151	1.323
July	19	1.070	1.122	1.018	1.305
Aug.	17	1.096	1.104	1.086	1.276
Sept.	17	1.122	1.192	1.089	1.291
Oct.	28	1.106	1.273	1.110	1.407
Nov.	25	1.039	1.075	0.983	1.334
Dec.	17	1.155	1.273	0.986	1.313

These values are the averages of the measurements made on 248 days during the 56 months, January, 1928, through August, 1932, and represent nearly half of the 530 clear days listed by the Weather Bureau. The curves in Fig. 1 illustrate the variations in the average noon intensities for the observation period. The

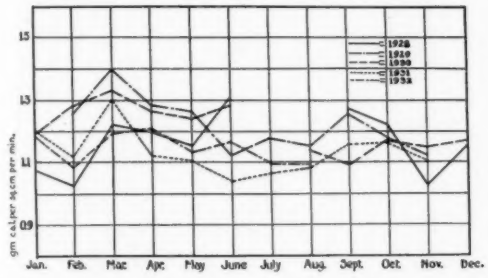

FIG. 1. Annual variation in noon radiation intensities. Solar radiation at normal incidence.

absolute maximum value of 1.450 g cal. per sq. cm per min. was reached at noon on March 23, 1929. High values over 1.4 g cal. per sq. cm were consistently recorded in March and less often in October. The highest values in 1928, 1.320 and 1.334 g cal. per sq. cm per min. were obtained on March 19 and October 19, respectively, and the values of 1.392 and 1.407 g cal. per sq. cm per min. on March 25 and October 31, 1930, of 1.407 on March 3, 1931, and of 1.387 on March 12, 1932, represent the maximum readings for these years. Dorno[10] found maximum energy values in February at Potsdam, and in March at Davos, and Kimball[1] obtained readings during March in Washington, D. C., Madison, Wisconsin, Lincoln, Nebraska and Santa Fe, New Mexico, which were as high as, or higher, than those found at other times of the year. Kimball points out that, generally speaking, in the northern hemisphere the water vapor content of the atmosphere increases at about the same time of the year that the earth's solar distance increases, so that with the sun at any given zenith distance the solar radiation intensity is much greater in winter than in summer, and in the early spring months than in the late fall. Our absolute maximum of 1.450 g cal. per sq. cm per min. is to be compared with 1.51, 1.44, 1.537 and 1.75 g cal. per sq. cm per min., the absolute maxima for Washington, D. C., Potsdam, Davos, Mt. Whitney and Mt. Wilson, respectively.

The averages for the various months listed in Table I are of the same order as those given by Kimball[1] for cities of latitude 30° N on the coast of the Gulf of Mexico. These values represent the amounts of radiation found on clear days only. Clouds, moisture, smoke and dust often decrease the total considerably. Thus on November 7, 1930, the sky was covered with fleecy clouds and the total solar radiation at noon was 0.875 g cal. per sq. cm per min. as contrasted with 1.334 g cal. per sq. cm per min. at noon on November 24, 1930, a clear bright day. Likewise, on clear but moist days in July or August the total energy is less than in December. The uncontrollable cloud and atmospheric conditions very often affect the results more conspicuously than does the time of day, so that the noon value quite often does not represent the maximum value for the day.

TOTAL SOLAR RADIATION ON A HORIZONTAL PLANE

The above values represent more or less momentary measurements of the amount of energy present in direct solar radiation on clear days, which, in New Orleans, are only about a third of the days in the year. In Table II are given the averages of total radiation (direct and diffuse) as determined from the continuous

[10] C. Dorno, Physik der Sonnen und Himmelsstrahlung, 1919.

TABLE II. *Average amount of total radiation (sunshine and skyshine) received on a horizontal surface (g cal./sq. cm/min.).*

Hour ending 1931	7	8	9	10	11	12	1	2	3	4	5	6	Average daily total
Mar.	0.062	0.155	0.337	0.541	0.625	0.723	0.676	0.636	0.508	0.424	0.154	0.048	293.3
Apr.	0.063	0.207	0.418	0.632	0.745	0.783	0.747	0.698	0.601	0.462	0.242	0.075	340.4
May	0.107	0.273	0.448	0.631	0.780	0.743	0.818	0.779	0.714	0.504	0.311	0.095	372.2
June	0.148	0.256	0.497	0.591	0.731	0.731	0.692	0.641	0.569	0.468	0.315	0.103	344.5
July	0.137	0.258	0.427	0.551	0.686	0.765	0.650	0.628	0.577	0.475	0.260	0.103	331.0
Aug.	0.133	0.281	0.446	0.630	0.701	0.761	0.713	0.601	0.533	0.428	0.275	0.090	335.5
Sept.	0.117	0.267	0.480	0.647	0.718	0.811	0.833	0.758	0.665	0.430	0.224	0.063	360.8
1932													
Jan.		0.053	0.156	0.302	0.422	0.515	0.486	0.423	0.329	0.212	0.089		179.2
Feb.	0.010	0.089	0.237	0.422	0.512	0.495	0.472	0.439	0.376	0.247	0.124	0.017	206.4
Mar.	0.034	0.150	0.315	0.472	0.585	0.637	0.650	0.619	0.493	0.348	0.184	0.051	272.3
Apr.	0.098	0.277	0.460	0.644	0.830	0.767	0.735	0.721	0.605	0.447	0.261	0.097	356.5
May	0.110	0.215	0.447	0.588	0.656	0.734	0.698	0.564	0.493	0.358	0.249	0.115	313.6
June	0.262	0.467	0.632	0.706	0.809	0.804	0.787	0.703	0.587	0.447	0.285	0.166	399.3
July	0.155	0.387	0.589	0.683	0.762	0.738	0.626	0.546	0.491	0.400	0.300	0.207	353.0
Aug.	0.123	0.293	0.479	0.558	0.621	0.587	0.562	0.499	0.381	0.285	0.201	0.104	281.6

TABLE III. *Average amount of total radiation (sunshine and skyshine) received on a horizontal surface on clear days only (g cal./sq. cm/min.).*

Hour ending 1931	7	8	9	10	11	12	1	2	3	4	5	6	Average daily total
Mar.	0.072	0.209	0.447	0.703	0.873	0.989	1.049	0.994	0.855	0.608	0.282	0.061	428.5
Apr.	0.067	0.260	0.549	0.810	0.984	1.086	1.070	1.015	0.851	0.651	0.326	0.080	464.9
May	0.134	0.324	0.587	0.790	0.976	1.057	1.133	1.063	0.914	0.654	0.384	0.105	487.3
June	0.125	0.433	0.706	0.725	1.009	1.058	1.069	1.070	0.940	0.729	0.445	0.149	507.5
July	0.188	0.345	0.543	0.771	0.900	1.054	1.034	1.045	0.875	0.653	0.343	0.109	471.6
Aug.	0.163	0.342	0.536	0.789	0.929	1.071	1.066	0.959	0.815	0.646	0.343	0.121	468.8
Sept.	0.122	0.293	0.537	0.720	0.882	1.011	1.092	0.959	0.831	0.550	0.282	0.085	441.8
1932													
Jan.		0.082	0.259	0.484	0.704	0.805	0.836	0.768	0.591	0.376	0.160		303.9
Feb.	0.018	0.155	0.374	0.606	0.746	0.834	0.803	0.720	0.595	0.415	0.217	0.029	330.7
Mar.	0.044	0.208	0.452	0.687	0.863	0.930	0.905	0.862	0.700	0.480	0.264	0.051	386.8
Apr.	0.114	0.325	0.574	0.779	0.932	1.002	0.947	0.881	0.716	0.502	0.292	0.102	430.0
May	0.178	0.426	0.645	0.780	0.961	1.072	1.023	0.889	0.778	0.620	0.396	0.166	476.0
June	0.269	0.484	0.682	0.790	0.978	1.057	1.052	0.935	0.804	0.594	0.377	0.186	492.5
July	0.224	0.440	0.628	0.810	0.958	1.057	1.031	0.893	0.665	0.553	0.333	0.165	465.4
Aug.	0.154	0.397	0.625	0.786	0.950	1.023	0.980	0.941	0.642	0.468	0.262	0.144	442.3

records obtained with the Eppley pyrheliometer for seven months in 1931 and eight months in 1932. Table III includes the clear days only for this period. In the last column is given the average total amount of radiation received daily on a horizontal surface.

The highest value recorded in 1931, 1.485 g cal. per sq. cm per min., was reached at noon on May 31, August 6 and September 14. The absolute maximum value for the first eight months of 1932, 1.501 g cal. per sq. cm per min., was recorded on May 23 at 11:30 A.M., on July 7 at noon, and on July 18 at 12:45 P.M. Values greater than 1.4 g cal. per sq. cm per min. are quite common, especially on days when cumulus clouds are in the neighborhood of the sun. The highest hourly averages on any one day were 1.26 and 1.312 g cal. per sq. cm per min. obtained from 11 A.M. to 12 M., and from 12 M. to 1 P.M., respectively, on May 24, 1931, a clear day. The average daily totals on clear days (last column, Table III) reflect the change in the altitude of the sun from the maximum in June and are of particular interest when compared with the similar, and practically more important, values for all days (last column, Table II) which show no such regularity since but a relatively small percentage of the total

number of days are clear, especially during the summer months.

Distribution of Energy

The average absolute and relative amounts of ultraviolet, luminous and infrared energy present in direct sunlight at normal incidence at noon on clear days are given in Table IV. In Table V is shown the energy distribution at 10 A.M., 12 M. and 2 P.M. on representative clear days during the four seasons. The absolute values vary, of course, with the total radiation, but the relative percentages of each part with respect to the total are quite consistent. With approximately similar total energy content, the red and short infrared energy (620$m\mu$ to 1.4μ) is higher during the winter and early spring months than in summer and fall, while the longer infrared (>1.4μ) shows a gradual increase of about 7 percent from winter to summer. The decrease in the red and short infrared parallels the increase in water vapor pressure, which is about two and a half times as high in July as it is in January. The luminous component (400 to 620$m\mu$) is very constant, showing a change of only 5 to 10 percent for equal solar altitudes throughout the year, the maximum for equal solar altitudes coming in the winter and the minimum in the summer. These findings in the luminous and

Table IV. *Energy distribution at noon on clear days. Direct solar radiation at normal incidence. Composite average for 56 months.*

	Total energy (g cal./cm²/min.)	<400$m\mu$ (g cal./cm²/min.)	Percent of total	400–620$m\mu$ (g cal./cm²/min.)	Percent of total	620$m\mu$–1.4μ (g cal./cm²/min.)	Percent of total	>1.4μ (g cal./cm²/min.)	Percent of total
Jan.	1.173	0.0143	1.2	0.414	35.4	0.499	42.5	0.246	20.9
Feb.	1.148	0.0194	1.7	0.409	34.7	0.459	40.0	0.261	23.6
Mar.	1.365	0.0510	3.7	0.512	37.5	0.468	34.2	0.335	24.6
Apr.	1.203	0.0289	2.4	0.448	37.2	0.428	35.6	0.298	24.8
May	1.126	0.0364	3.2	0.424	37.7	0.400	35.5	0.266	23.6
June	1.185	0.0389	3.3	0.449	37.9	0.382	32.2	0.315	26.6
July	1.145	0.0326	2.9	0.450	39.3	0.348	30.4	0.314	27.4
Aug.	1.128	0.0363	3.2	0.464	41.2	0.334	29.6	0.294	26.0
Sept.	1.189	0.0349	2.9	0.494	41.6	0.385	32.4	0.275	23.1
Oct.	1.178	0.0370	3.1	0.463	39.3	0.400	34.0	0.278	23.6
Nov.	1.091	0.0246	2.3	0.451	41.3	0.364	33.3	0.252	23.1
Dec.	1.303	0.0186	1.4	0.556	42.6	0.462	35.6	0.266	20.4

Table V. *Energy distribution on representative clear days.*

Date	Time	Total energy (g cal./cm²/min.)	<400$m\mu$ (g cal./cm²/min.)	Percent of total	400–620$m\mu$ (g cal./cm²/min.)	Percent of total	620$m\mu$–1.4μ (g cal./cm²/min.)	Percent of total	>1.4μ (g cal./cm²/min.)	Percent of total
1930										
Jan. 8	10:00	1.068	0.0098	0.92	0.346	32.4	0.407	38.1	0.305	28.6
	12:00	1.152	0.0147	1.28	0.396	34.4	0.461	40.0	0.280	24.3
	2:00	0.988	0.0099	1.00	0.357	36.1	0.321	32.5	0.300	30.4
Mar. 10	10:00	1.362	0.0163	1.20	0.456	33.5	0.492	36.1	0.398	29.2
	12:00	1.391	0.0599	4.30	0.491	35.3	0.442	31.8	0.398	28.6
	2:00	1.204	0.0355	2.95	0.397	33.0	0.393	32.7	0.378	31.4
July 6	10:00	1.247	0.0249	2.00	0.591	47.4	0.410	32.9	0.221	17.7
	12:00	1.276	0.0276	2.16	0.606	47.5	0.355	27.8	0.287	22.5
	2:00	1.290	0.0200	1.55	0.595	46.1	0.386	29.9	0.289	22.4
Oct. 8	10:00	1.014	0.0162	1.60	0.484	47.7	0.369	36.4	0.145	14.3
	12:00	1.167	0.0286	2.45	0.526	45.1	0.396	33.9	0.216	18.5
	2:00	1.038	0.0218	2.10	0.425	40.9	0.386	37.2	0.206	19.8

infrared are similar to those obtained by Dorno[10] at Davos (altitude 1560 m) and at Muottas-Muraigl[11] (altitude 2456 m).

The greatest daily, yearly, and seasonal variation is found in the ultraviolet, particularly in the short ultraviolet, since this component is markedly influenced by the altitude of the sun and by atmospheric conditions. Not only is the highest absolute average amount of ultraviolet found in March, but the relative percentage of the total is greatest. The absolute maximum amount of ultraviolet was found on March 31, 1930, a value of 0.0758 g cal. per sq. cm per min. which represented 5.5 percent of the total radiation. Values exceeding 0.05 g cal. per sq. cm per min. were found in every month except December, January, February and April, the maximum value for the latter month being 0.0468 g cal. per sq. cm per min. For an equally high sun (noon in December and about 4 P.M. in June) the maximum ultraviolet value is found in winter and the minimum in summer, and for equal solar altitude the value in October (noon) is higher than in March (10 A.M.). Dorno also found this to be true in Davos and Muottas-Muraigl.

The variations in the antirachitic part of the spectrum (wave-lengths shorter than $313m\mu$) reflect, more than any other part of the spectrum, the local atmospheric conditions obtaining at the time of measurement. Fig. 2 illustrates the seasonal variation in the antirachitic energy as obtained from averages for the respective months of the years 1930 and 1931 at 10 A.M. and at noon. The curves show a pronounced dip during February, due, in large measure, to the high humidity and water vapor pressure which prevailed during this month. The water vapor pressure at noon on the days measured during January averaged 8.85 and 5.46 mm in 1930 and 1931, respectively, the corresponding values for February being 10.2 and 6.1 mm, respectively. Since the amount of antirachitic radiation present during the month is relatively small, the reduction in energy is considerable. The absolute maximum value was obtained at 1 P.M. on July 13, 1932, 0.001396 g cal. per sq. cm per min. ($97.7\mu w$) which represented 0.142 percent of the total radiation and 3.8 percent of the total ultraviolet radiation. High values were usually recorded on clear days after hard rains during the night, as, for example, on December 29, 1930, when the antirachitic energy at noon was equivalent to 0.000552 g cal. per sq. cm per min. ($38.6\mu w$), approximately 40 percent of the absolute maximum and as high as some of the values for the spring and fall months. These values for the antirachitic radiation must be taken to represent the upper limit to be expected under the most ideal conditions. There are many days, even in July and August when, because of weather conditions no antirachitic radiation is present even at noon. In fact, the average noon value for January, 1931, is as high as that for April, 1931, and the latter value is less than 60 percent of the average for the same month in the previous year. The extreme variability of this component is perhaps best illustrated by the following example. On October 13, 1930, the antirachitic energy at 11:45 A.M. was equivalent to 0.000659 g cal. per sq. cm per min. A few cirrus clouds were in the vicinity of the sun. Fifteen minutes later, these clouds had disappeared and the energy increased to 0.000736 g cal. per sq. cm per min., an increase of over 11 percent. Our results emphasize that the ultraviolet solar radiation, particularly the antirachitic component, cannot be evaluated, or even roughly guessed at, from conditions ordinarily observable, such as clearness of the sky, time of day, humidity, etc., but must itself be specifically measured. Our values for this region

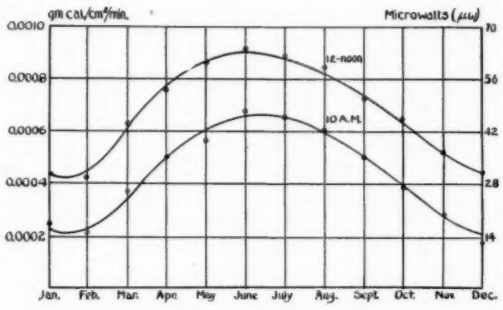

FIG. 2. Annual variation in short ultraviolet ($<313m\mu$) intensities. Solar radiation at normal incidence.

[11] C. Dorno, Grundzüge des Klimas von Muottas-Muraigl, 1927.

TABLE VI. *Comparison of midday energy values of wave-lengths less than 313mμ.*

Authors	Location	Midsummer (g cal./ cm²/min.)	Midsummer μw/ sq. cm	Midwinter (g cal. cm²/min.)	Midwinter μw/ sq. cm
Greider and Downs	Springfield Lake, O. Alt. 1200 ft. (366M.)	0.00043	30	0.00023	16
Greider and Downs	Cragmoor, Colo. Alt. 6500 ft. (1981M.)	0.00098	69	0.00030	21
Pettit	Estimate for mid-latitude, sea level	0.00129	90	—	—
Coblentz and Stair	Washington, D. C. Alt. 350 ft. (107M.)	0.00129	90	0.00029	20
Luckiesh	Estimate from erythemal observations	0.00047–0.00057	33–40	—	—
Clark	Baltimore, Md.	0.00860	602	0.00072	50
Laurens and Mayerson	New Orleans, La. Alt. 100 ft. (26M.)	0.00099	69	0.00040	28

of the spectrum are in general agreement with those of other investigators.[7] In Table VI is given a comparison of the estimates of various workers in different parts of the country. Clark's values[12] are considerably higher than those of other investigators, due, we suspect, to the fact that there has been no reduction for the amount of energy of wave-lengths longer than 313$m\mu$ which are included in the measurement of wave-lengths shorter than 313$m\mu$ when a window glass filter is used.

Measurement of the short wave limit of the solar spectrum with a Zeiss, as well as with a Gaertner quartz spectrograph on panchromatic plates shows that very seldom does it extend to 300$m\mu$ even at midday on the clearest days in midsummer. Table VII shows the longest and shortest wave-length limit at 10 A.M., 12 M. and 2 P.M. for the years 1929, 1930 and 1931. On only one day, June 6, 1930, at 10 A.M. did the spectrum extend to 299$m\mu$, and even on this day the short wave limit at noon was 303$m\mu$. During the winter months the spectrum rarely extends below 306$m\mu$ except on very clear days after a storm when the air has been washed clean. Only seven out of a total of forty-six spectrograms taken during December, January and February show wave-lengths shorter than 306$m\mu$, and only two show wave-lengths as short as 300$m\mu$. Spectrograms taken during the spring, summer and fall indicate the presence of wave-lengths shorter than 302$m\mu$ on only eleven days, the limit in the majority of the clear days being about 304$m\mu$. Clouds, haze and air pollution decrease the extent of the spectrum so that, even in July and August, no wave-lengths shorter than 310$m\mu$ are present. Our data indicate that although on some days in midwinter there is considerable antirachitic radiation, seldom does it contain wave-lengths shorter than 306$m\mu$, while the antirachitic effect during the rest of the year is mediated chiefly by wave-lengths longer than 302$m\mu$.

[12] J. H. Clark, J. Opt. Soc. Am. 21, 240 (1931).

TOTAL ENERGY AND DISTRIBUTION OF SKYSHINE

The radiation from the sky, exclusive of direct sunlight, has been for the most part

TABLE VII. *Limits of spectrum on clear days (1929 through August, 1932).*

Month	10:00 A.M. High	10:00 A.M. Low	12:00 M. High	12:00 M. Low	2:00 P.M. High	2:00 P.M. Low
Jan.	313	303	311	300	312	306
Feb.	309	304	308	300	313	308
Mar.	313	303	308	300	311	304
Apr.	309	302	308	300	311	304
May	311	304	309	303	309	306
June	308	299	310	303	308	305
July	307	304	304	302	308	304
Aug.	309	304	309	302	309	306
Sept.	311	307	314	305	312	307
Oct.	315	303	312	300	313	305
Nov.	311	309	313	307	318	307
Dec.	311	308	309	306	312	308

neglected, and one finds but scattered references to it as compared with the emphasis placed on direct solar radiation. On clear days at noon the sky contributes between 7 and 17 percent of the total (sun and sky) radiation. The presence of clouds in the vicinity of the sun but not obscuring it considerably increases the percentage of the total contributed by the sky. (Table VIII.)

TABLE VIII. *Percentage of total energy (sun and sky) contributed by sky. (Noon values in g cal./sq. cm/min.).*

Date 1931	Sky conditions	Sun and sky	Sky	Percent of total
Apr. 6	clear	0.868	0.134	15.4
" 24	cumulus, fleecy clouds	0.734	0.228	31.0
June 1	clear	1.219	0.094	7.7
" 18	fleecy clouds	0.649	0.174	26.8
July 2	fleecy clouds	0.898	0.201	22.3
" 9	clear	1.040	0.107	10.3

The total energy and distribution of skyshine for representative clear days are given in Table IX. In general, the total energy of skyshine increases with increase in solar altitude (Table X) but shows much less daily and seasonal variation than does that of direct sunshine. Between the hours of 10 A.M. and 2 P.M. the luminous component (400–620$m\mu$) comprises between 30 to 40 percent of the total energy of skyshine or about one-fourth to one-eighth that found in sun and sky. Between 10 A.M. and 2 P.M. the infrared radiation (longer than 620$m\mu$) forms about 20 to 30 percent of sky radiation or between one-fifteenth and one-thirtieth of the total infrared radiation found in sun and sky. The luminous and infrared components show a gradual, slight increase in the summer months paralleling in general the increase in total sky radiation.

The remainder of the energy (40 to 50 percent) is in the ultraviolet. Skylight, it is to be recalled, is nothing more than sunlight scattered by the

TABLE IX. *Distribution of solar energy as measured on a horizontal surface (g cal./sq. cm/per min.).*

Date	Time	Total energy	<313$m\mu$	<400$m\mu$	400–620$m\mu$	>620$m\mu$
			Sun and sky			
1932						
Jan. 19	10:30	0.665		0.103	0.186	0.376
	12:10	0.845	0.000456	0.090	0.234	0.521
	3:00	0.540	0.000226	0.049	0.125	0.366
Apr. 13	10:00	1.000	0.001001	0.174	0.289	0.537
	12:10	1.120	0.002060	0.168	0.266	0.686
	2:30	0.890	0.000932	0.150	0.251	0.489
July 13	10:00	0.880		0.102	0.223	0.555
	12:20	1.080	0.002551	0.196	0.235	0.649
	3:20	0.620	0.002410	0.043	0.136	0.441
1931						
Oct. 12	11:00	0.840	0.000800	0.087	0.241	0.512
	12:00	0.987	0.001070	0.144	0.260	0.583
	1:30	0.824		0.070	0.248	0.506
			Sky only			
1932						
Jan. 19	10:30	0.0715		0.0325	0.0270	0.0120
	12:10	0.0785	0.000238	0.0311	0.0289	0.0185
	3:00	0.0635	0.000204	0.0326	0.0218	0.0091
Apr. 13	10:00	0.1080	0.000099	0.0503	0.0393	0.0184
	12:10	0.1120	0.000620	0.0510	0.0367	0.0243
	2:30	0.1010	0.000740	0.0519	0.0394	0.0097
July 13	10:00	0.1160	0.000136	0.0445	0.0432	0.0283
	12:20	0.1350	0.000873	0.0489	0.0464	0.0397
	3:20	0.0950	0.000646	0.0475	0.0402	0.0073
1931						
Oct. 12	11:00	0.0907	0.000387	0.0305	0.0389	0.0213
	12:00	0.1056	0.000475	0.0385	0.0401	0.0270
	1:30	0.0824		0.0340	0.0349	0.0135

TABLE X. *Increase in total energy of skyshine with solar altitude. Measured on a horizontal surface in g cal./sq. cm/min.*

Solar altitude	40°	50°	60°	70°	80°	90°
Total energy	0.0730	0.0795	0.1013	0.1054	0.1108	0.1370

TABLE XI. *Comparison of solar and sky ultraviolet (<400mμ) (g cal./sq. cm/min. on a horizontal surface).*

Solar altitude	40°	50°	60°	70°	80°	90°
Sun	0.0327	0.0420	0.0515	0.0576	0.0804	0.1166
Sky	0.0336	0.0313	0.0420	0.0445	0.0613	0.0714
Sun and sky	0.0663	0.0733	0.0935	0.1021	0.1417	0.1880
$\frac{\text{Sun}}{\text{Sky}}$ (sky = 100)	0.97	1.34	1.23	1.29	1.31	1.63

TABLE XII. *Comparison of solar and sky antirachitic radiation (<313mμ) (g cal./sq. cm/min. on a horizontal surface).*

Solar altitude	50°	60°	70°	80°	90°
Sun	0.000285	0.000447	0.000560	0.000800	0.001395
Sky	0.000133	0.000217	0.000348	0.000418	0.000754
Sun and sky	0.000418	0.000664	0.000908	0.001218	0.002149
$\frac{\text{Sun}}{\text{Sky}}$ (sky = 100)	2.14	2.06	1.61	1.91	1.85

atmosphere. The scattering is inversely proportional, in a perfectly dry, dust-free atmosphere, to the fourth power of the wave-length and therefore the ultraviolet is relatively much more increased than the other components. In Table XI is given a comparison of the ultraviolet ($<400m\mu$) in sunshine and in skyshine and their ratio at different solar altitudes. At a solar altitude of about 40° the sky furnishes over 50 percent of the total ultraviolet found in sunshine and skyshine while at greater solar heights, the relative increase in solar ultraviolet is greater (see also Pettit[13] and Dorno[11]). Even at a solar altitude of 90°, however, the sky still furnishes over 26 percent of the total ultraviolet. With the sun at equal heights there is more ultraviolet in sky radiation in autumn than in spring (see also Dorno[11]).

Although the importance of the short ultraviolet radiation ($<313m\mu$) in heliotherapy has now been definitely indicated, it is not generally recognized that a considerable amount of this effective energy is furnished by the sky. Table XII represents a comparison of the amounts of antirachitic radiation present in sun and in sky and their ratio. The actual amounts in sunshine and in skyshine increase with solar altitude, but the ratio remains surprisingly constant. The highest value, 0.000873 g cal. per sq. cm per min. ($61.1\mu w$) was obtained in July 13, 1932, at 1:00 P.M. (solar altitude about 85°). This value represents about 0.6 percent of the total energy and about 2 percent of the total ultraviolet radiation in skyshine at that time. It is to be compared with the maximum reading of 0.001396 g cal. per sq. cm per min. ($98\mu w$) for the antirachitic radiation as received from direct sunshine measured at normal incidence over a period of fifty-six months. It is clear, therefore, that on many days, particularly when the sun is low and there are clouds in its vicinity, there is as much antirachitic radiation in skyshine as in sunshine and often considerably more.

Our biological investigations[2, 3, 4] on the antirachitic efficiency of New Orleans sunshine indicate that there is ample antirachitic energy in sunshine and skyshine and in skyshine alone in New Orleans to promote normal growth and calcification in chicks and to prevent rickets in rats throughout the year. Application of the data presented in this paper indicates that antirachitic radiation equivalent to a total of about 0.049 g cal. per sq. cm as obtained either from sun and sky, sky alone, or from artificial sources and distributed over a period of five weeks will prevent the appearance of rickets in rats, while a total of 0.0563 g cal. per sq. cm (0.00134 g cal. per sq. cm daily for forty-two days) will provide for normal calcification and growth of chicks.

SUMMARY

The intensity and distribution of solar radiation have been measured over a period of fifty-six months by the radiometric method. Maximum values for solar radiation at normal incidence were obtained in March and October equivalent to over 1.4 g cal. per sq. cm per min. Continuous records of total solar radiation on a

[13] E. Pettit, 1928. Quoted from Coblentz, W. W. and R. Stair: Bur. Standards J. Research 6, 951 (1931).

horizontal plane (sun and sky) on clear days, for seven months in 1931 and eight months in 1932, showed a maximum in June. When all days, clear and cloudy, are included the highest average daily total was obtained in May in 1931 and in June in 1932.

The red and short infrared energy (620$m\mu$ to 1.4μ) of direct solar radiation is higher in the early spring months than in summer and fall, while the longer infrared (>1.4μ) shows a gradual increase from winter to summer. There is relatively little seasonal variation in the luminous component (400–620$m\mu$). The ultraviolet radiation fluctuates considerably, values over 0.05 g cal. per sq. cm per min. (approximately 5 percent of the total radiation) being found in all except the winter months and April.

The antirachitic radiation (<313$m\mu$), the most variable of the components, increases from about 0.0004 g cal. per sq. cm per min. (28μw) in winter to about 0.0014 g cal. per sq. cm per min. (98μw) in summer. Wave-lengths shorter than 306$m\mu$ are seldom found in winter, and the effective antirachitic radiation during the rest of the year is composed of wave-lengths longer than 302$m\mu$. Only one spectrogram taken on June 6, 1930, at 10 A.M. showed the presence of the wave-length 299$m\mu$.

The energy content of sky radiation increases from about 0.06 g cal. per sq. cm per min. in the winter to about 0.13 g cal. per sq. cm per min. in the summer. On clear days at noon it furnishes 7 to 17 percent of the total (sun and sky) radiation. From 20 to 30 percent of this energy is in the infrared (>620$m\mu$), 30 to 40 percent in the luminous (400–620$m\mu$) and the remainder is in the ultraviolet. Throughout the year skyshine contains at least one-half as much antirachitic radiation (<313$m\mu$) as does direct sunshine.

Experiments with the Bubble Sextant at Sea

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(Received February 9, 1933)

Altitudes of celestial objects were observed with the bubble sextant from a 950 ton ship and a 12 ton craft at sea. For moderate sea conditions individual altitudes were occasionally as much as 60 minutes of arc in error and averages of 5 consecutive observations were usually correct within 30 minutes of arc. On the 950 ton ship a portion of the error was due to the vibration of the ship caused by wind, engines, etc., and a larger portion was due to the horizontal acceleration arising from the roll and pitch of the ship. If the roll were simple harmonic the latter error could be partially eliminated by taking the sextant altitude at the midpoint of the roll. A small pendulum device was arranged to sound a buzzer signal at the midpoint of the roll and the sextant observations were made simultaneously with the buzzer signal. This improved the accuracy of the bubble sextant altitudes by roughly a factor of 2, so that individual observations were rarely more than 30 minutes of arc in error and averages of 5 consecutive altitudes were usually correct within 15 minutes of arc for a moderate sea.

I. INTRODUCTION

ON a ship at sea an artificial horizon, such as a pool of mercury or a bubble in a liquid like a spirit level, is unsteady because of the motion of the ship. Altitudes measured from the artificial horizon are not very accurate. This disadvantage has been great enough to prevent its use almost entirely, in spite of the fact the occasions arise when the navigator might be glad of even a somewhat uncertain horizon rather than none at all. In recent years, however, the bubble sextant has been brought to a fairly high state of perfection because of the demands of aviation, for the simple reason that the navigator of an airplane rarely has a natural horizon satisfactory for celestial navigation and must, perforce, provide himself with an artificial horizon.

Little definite information was available about the use of the later types of bubble sextants[1] on surface ships and the present experiments were done to find out what accuracy could be obtained with them. Observations were made on the *USS Cormorant*, length 180 feet, beam 36.5 feet, displacement 950 tons, and on a small craft 30 feet in length, displacement 12 tons. An instrument called the "midpoint indicator" was investigated, the instrument being designed to eliminate to some extent the bubble sextant errors due to the motion of the ship.

The observed bubble sextant altitudes corrected for atmospheric refraction are plotted as dots in Figs. 1 and 2 against the time as abscissa. The dots are joined by straight lines. The observations were taken at time intervals of about a minute, the sextant being moved and the setting changed between observations, so that each observation was made afresh and was therefore entirely independent of the preceding ones. The dotted lines in the figures are the true altitudes calculated from the known position and the time. It may be recalled that a difference between the sextant altitude and the true altitude of one minute of arc amounts to an error of one nautical mile in the position of the ship calculated from the sextant altitude. The crosses along some of the curves of Figs. 1 and 2 are the averages of each five consecutive observations. A detailed discussion of the data of the figures is given in later paragraphs.

II. BUBBLE SEXTANT ERRORS

The bubble sextant errors on a ship at sea arise from two classes of disturbances of the bubble, those of quick period, less than one second, and those of slow period, greater than

[1] Descriptions of and experiments with artificial horizon sextants, mostly from the standpoint of aerial navigation, are given by Eaton, Report No. 131, 1922, and Beij, Report No. 198, 1924, Nat. Advisory Committee for Aeronautics; H. N. Russell, Proc. Ast. Soc. Pacific **31**, 129 (1919); Gatty, Jr. Soc. Aut. Eng. **30**, 153 (1932).

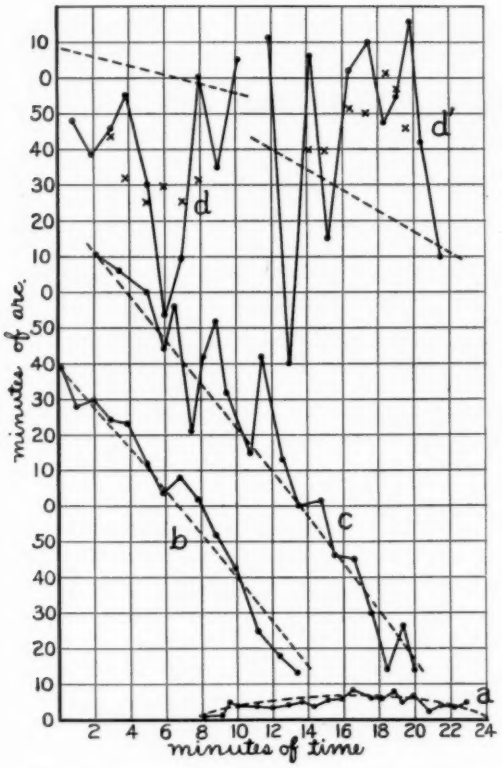

FIG. 1. Dots are bubble sextant altitudes, crosses are averages of five consecutive dots, broken lines are true altitudes. *a*, sun, observed from land; *b*, sun, observed while under way at 12 knot speed in Chesapeake Bay; *c*, sun, observed while at anchor in a moderate sea, roll 2° to 4°; *d* and *d'*, star Rigel, observed while under way at 12 knot speed in a moderate sea. *b*, *c*, *d* and *d'* were observed from the *USS Cormorant*.

several seconds. The two classes are fairly well defined on a large ship. The quick period disturbances are caused by vibration of the ship due to the engines, wind and the slap and crash of waves against the ship. The slow period disturbances are caused by the roll and pitch of the ship, and on large ships may be much greater than the quick period disturbances. On small craft the quick period disturbances are the ones mainly noticeable.

To estimate the error due to roll we make use of the fact that a point on a ship, say, on the bridge, often executes approximately a simple harmonic motion as the ship rolls. An examination of the rolling curves of large ships in moderate weather showed them to be sine curves to a fair approximation, although of course the amplitude varied somewhat and other periods than the fundamental were present to some extent.

Assume that a point on the bridge of the ship moves according to

$$x = x_0 \sin (2\pi/p)t, \tag{1}$$

where x is the distance of the point at time t from its position at the midpoint of its oscillations to and fro, x_0 is the amplitude, i.e., the distance from the midpoint to the extreme displacement, and p is the period, i.e., the time for a complete oscillation. If the ship rolls about a longitudinal axis somewhere near the water line and if h is the height from the water line to the bridge,

$$x_0 = h \tan \alpha_0, \tag{2}$$

where α_0 is the extreme angular displacement from the midpoint of the roll. The acceleration f in the horizontal plane in the direction across ship is d^2x/dt^2, neglecting any vertical displacements, and from (1) and (2)

$$f = -(4\pi^2/p^2)h \tan \alpha_0 \sin (2\pi/p)t. \tag{3}$$

In this direction a pendulum will deviate from the vertical by an angle d, or the horizon indicated by a bubble sextant will deviate from the true horizon by an angle d, where

$$d = \tan f/g, \tag{4}$$

g being the acceleration of gravity. In any other direction θ, where θ is the angle with the fore-and-aft line of the ship, the acceleration due to the roll is $f \sin \theta$.

For normal average conditions at sea we have for a destroyer $p = 10$ sec., $\alpha_0 = 10°$, $h = 22$ feet and for a battleship $p = 15$ sec., $\alpha_0 = 5°$, $h = 68$ feet. For these two cases the maximum value of d from (3) and (4) was 163 and 108 minutes of arc, respectively. The calculation shows that the errors due to roll may be very large. They can be reduced to some extent by averaging a long series of observations, but in practice it turns out that the average of five consecutive observations may often be more than 20 minutes of arc in error.

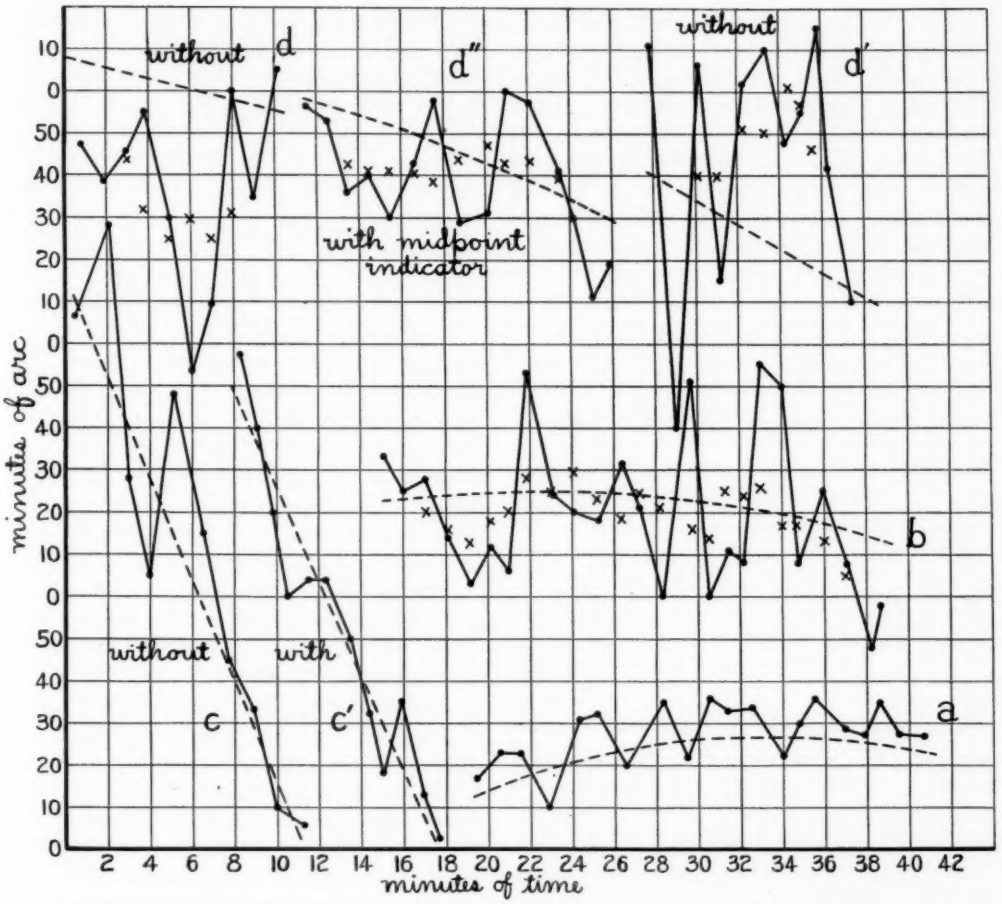

FIG. 2. Dots are bubble sextant altitudes, crosses are averages of five consecutive dots, broken lines are true altitudes. *a* and *b*, sun, observed from a 30 foot ketch sailing over a smooth and a moderate sea; *c* and *c'*, star Altair, observed while at anchor in a moderate sea, roll 2° to 7°, with and without the midpoint indicator; *d*, *d'* and *d''*, star Rigel, observed while under way at 12 knot speed in a moderate sea, roll up to 7°, with and without the midpoint indicator. *c*, *c'*, *d*, *d'* and *d''* were observed from the *USS Cormorant*.

III. Observations on Land

In *a*, Fig. 1, is given a typical series of observations taken on land sitting on a stool out of the breeze with no support for the arms. It is seen that individual observations are usually correct to within three minutes of arc. The data, however, demonstrate nothing more than that the observer was capable of using the instrument and thus his hands were fairly steady. If the instrument had been mounted in a firm clamp stand the errors would have been less, and the conclusion is merely that the observer turned himself into a clamp stand with moderate success. Standing up increases the errors, and standing in a breeze increases them still more, simply because the observer's unsteadiness is thereby increased.

IV. Observations on USS Cormorant

All of the observations on the *Cormorant* were taken from a station about 30 feet above the water line. The station was surrounded by the usual canvas railing about five feet high which protected the observer from the main breeze.

He was, however, subjected to puffs and eddies of air and to considerable vibration in addition to the motion due to the rolling and pitching of the ship. The station was chosen as being representative of fairly agitated conditions.

In taking altitudes the observer tried to steady himself as much as possible by bracing himself against the rail or stanchion. The size of the bubble in the sextant is adjustable and it was found best to use a rather large bubble for the sun, moon or stars, the bubble diameter being three or four times the diameter of the image of the sun seen in the field. This gave the bubble a quick period so that it would respond readily to the various forces acting on it due to gravitation and ship movements. A small bubble is more sluggish than a large bubble and does not move about so quickly. True, it is steadier than a large bubble, but the steadiness is deceptive and usually harmful for it may lead to very erroneous readings. The point to be made may be put as follows: The artificial horizon is in effect a pendulum which, if acted on only by gravity, would hang vertically downward. On a moving ship there are present numerous other forces with components in the horizontal plane which disturb the pendulum from the true vertical. These come and go and change quickly and irregularly; they cannot be eliminated directly. All that one can do is to try to average them out as well as possible, and to do this he must have a highly damped, quick period pendulum which responds quickly and faithfully to all the forces acting on it. The bubble adjusted to a large size satisfies these requirements fairly well.

The best way to take an altitude is to bring the celestial body into or near the center of the field of view and to keep it there by tilting the sextant in sympathy with the motion of the ship, just as one does with an ordinary horizon sextant. Meanwhile the sextant is adjusted until the bubble oscillates to and fro equally above and below the image. This procedure amounts to averaging out approximately the effects of the disturbing forces. As might be expected the ship motion and hence the bubble movements are often so irregular that no exact judgment can be formed as to a correct setting. Watching the bubble for a longer time is of no help for it only continues the maze of irregularities. The thing for one to do is to put his attention on the bubble movements for a few seconds, say 10 to 20, record his reading and repeat the process.

In *b*, *c*, *d* and *d'*, Fig. 1, are given data which enable a rough comparison of the factors which caused the bubble errors. *b* was the case of vibration, due to wind, engines, etc., but no roll. *c* was the case of roll (and pitch) with but little vibration. *d* and *d'* were the case of both together. A rough conclusion is that moderate roll causes greater errors than moderate vibration. For *b* the *Cormorant* was underway in the Chesapeake Bay at a speed of 12 knots against a northerly breeze of 20 to 25 miles per hour. There was no roll or pitch but there was considerable vibration due to wind, the engines and impacts of waves against the ship. For *c* the *Cormorant* was at anchor in the open sea about 35 miles east of Chesapeake Lightship. The sea was moderate, there was little vibration. The ship rolled 2° to 4° (the complete amplitudes of the roll were twice these numbers), with some yaw so that the roll was irregular. In *d* and *d'* the *Cormorant* was running in the open sea at 12 knot speed. The sea was moderate, the ship rolled up to 7° and there was considerable vibration.

It is seen from *d* and *d'*, Fig. 1, that for the *Cormorant* underway in a moderate sea individual observations were occasionally as much as 60 minutes of arc in error and that averages of five consecutive observations were usually correct to within 30 minutes of arc. This agrees roughly with the calculations of Section II.

V. Observations on a Small Craft

Bubble sextant observations were made from the deck of a 12 ton ketch, over-all length 30 feet and beam 10 feet, sailing at sea. *a*, Fig. 2, gives some typical results for a calm sea and *b*, Fig. 2, for a moderate sea. In the latter case there was a long swell perhaps 6 feet high on which was superimposed a small chop 2 to 4 feet high. In this case, although the sea would be termed moderate, the little ship was quite agitated from the point of view of the bubble sextant.

VI. Observations with the Midpoint Indicator

If the ship is rolling with simple harmonic motion the horizontal acceleration at the midpoint of the roll is zero, as seen from (3). Therefore at this point the bubble indicates the true horizontal plane, provided there are no other disturbances, and if the observer takes the altitude at this point his observation is correct. This fact is well known and has recently been mentioned by Kaster.[2]

A small instrument, called the "midpoint indicator," was arranged to sound a buzzer signal at the midpoint of the roll. The indicator is sketched, somewhat diagrammatically in Fig. 3, a photograph is given in Fig. 4. A stand *H*, Fig. 3, carried a board *F*. Attached to *F* was another board *E* arranged to turn about pivot *M* through an angle of about 40° by means of a worm screw *W* and knob *K*. Board *E* carried a pendulum *P* 14 cm long hung at pivot *A*. The period of the pendulum was about 0.7 sec. and no damping was found necessary. Contact *C* was at the midpoint of scale *S* and every time the pendulum swung past *C* contact was made and an electrical circuit was closed which consisted of a battery *N* and a buzzer *B*. The entire instrument with battery, buzzer and a small light for illuminating scale *S* at night was in a water-tight case.

The midpoint indicator was placed on the deck, or convenient platform, near enough for the buzzer to be easily heard, usually within 50 feet, with the plane of board *E* or *F* in line with the bearing of the celestial object under observation. In general, *C* was not at the midpoint of the excursions of the pendulum to and fro, for the ship had a list, or the shelf or deck where the instrument stood was sloping. Board *E* was rotated about *M* by turning knob *K* until *C* was at the midpoint of the swings of *P*. The buzzer then sounded every time the ship passed through the midpoint of the roll. Looking into the bubble sextant one saw the image of the celestial object in the field, and kept it there by continually tilting the sextant in accord with the movements of the ship. The bubble was seen to make excursions up and down across

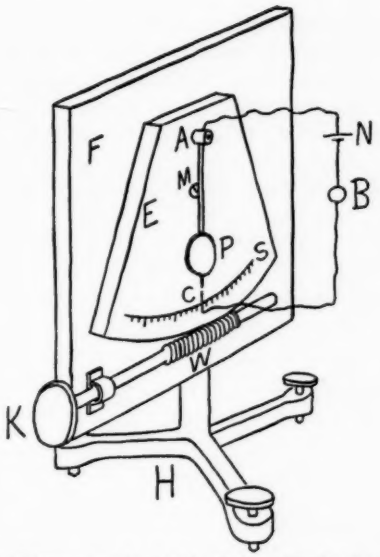

Fig. 3. Diagrammatic sketch of the midpoint indicator.

the field, and hence across the image of the celestial object, with a regularity in keeping with the regularity of the ship movements. If the ship movements were irregular so were

Fig. 4. Photograph of the midpoint indicator.

[2] Kaster, Proc. U. S. Inst. Naval Eng. **56**, 607 (1930).

the bubble movements, and so were the buzzes of the midpoint indicator. One then adjusted the sextant until the bubble was seen to swing across the celestial image at the instant the buzzer sounded. This called for an adjustment of the simultaneous coincidence of three moving things, bubble, image and buzz, which in practice was easy to do.

Curves c and c', Fig. 2, show altitudes of Altair taken with and without the midpoint indicator. In this case the *Cormorant* was at anchor in a moderate sea. Altair was nearly abeam and the ship rolled up to 7°. Curves d, d' and d'', Fig. 2, give three sets of altitudes of Rigel bearing abeam taken as the *Cormorant* steamed in a moderate sea at 12 knots, the first set taken without the midpoint indicator, the second with it and the third without it. The sea was moderate, the ship rolled up to 7° and there was considerable vibration. It is seen that the use of the midpoint indicator improved the accuracy of the bubble sextant altitudes to some extent. It reduced the extreme errors of individual observations, which were sometimes as much as 60 minutes of arc when it was not used, by roughly a factor of 2. The averages of 5 consecutive readings, shown by the crosses in d, d' and d'', without the midpoint indicator were often as much as 30 minutes of arc in error, whereas with it the averages were usually less than 15 minutes of arc in error.

A point to be mentioned about the midpoint indicator is that if improperly adjusted it may lead to a systematic error. If it is adjusted so that the buzz does not occur at the midpoint of the roll, but occurs always to one side of the midpoint, then the bubble sextant readings will on the average be too high (or too low). Experiments showed, however, that systematic errors of this sort were not likely to be of sufficient magnitude to be noticeable amid the other errors due to irregularities. In other words, the conclusion was that if the movements of the ship were regular enough to permit the establishment of the midpoint of the roll, there was no difficulty in establishing the midpoint with all desired accuracy.

The improvement of the use of the bubble sextant occasioned by the use of the midpoint indicator should be greater on larger ships than was the case on the *Cormorant*, simply because the larger the ship the more regular is its roll and pitch. Further experiments on different types of ships under a variety of weather conditions would be of interest. In such experiments various stations on the ship might be worth investigating. It would seem that high up on the bridge of the ship is not the best place to use the bubble sextant, a lower station near the water line amidships might be better.

American Secretariat Reports at 1931 Meetings of the International Commission on Illumination*

(Received January 5, 1933)

THE International Commission has built up a series of technical committees, the secretariats for each being assigned to one of the member countries. It is the duty of each Secretariat to survey its field, usually by means of an international questionnaire, and compile a report presenting facts and opinions of interest, and recommending action to be taken at the plenary meetings. Four such reports were submitted by United States Secretariats to the Cambridge meetings in September 1931, namely: Aviation Lighting, Lighting of Factories and Schools, Automobile Headlighting and Lighting Applications. Reprints of these reports have recently been received. A brief summary may be of interest.

Aviation Lighting

Aviation Lighting, which was treated in six sections comprises a pamphlet of 98 pages. The first section proposed definitions for the principal terms special to this field, the English, French and German equivalents being given so far as they were available. Section 2 is a tabular comparative statement of prevailing lighting practice, contributed by Great Britain, Germany, Switzerland and the United States. The remaining sections are reports by American Committees on lighting practice in this country covering Airports, Airways, Airplanes and Color Specifications.

Fourteen recommendations based principally upon this report were adopted at Cambridge enunciating rules of practice. The terms and definitions were not finally adopted but are considered to be under development and coordination and presumably will be considered at the 1934 meetings in Germany. Following the Cambridge meetings this subject was split up, Aviation, Ground Lighting going to the British Secretariat and Aircraft Lighting remaining in this country. Because of the great importance of coordination among European countries, a meeting under the auspices of the British Secretariat has subsequently been held at Zurich, Switzerland, where lighting and signalling practices were further discussed.

Factory and School Lighting

Following the mandate of the Saranac Meeting in 1928 the Secretariat secured international comments, and proposed a table of illumination levels to be recommended as good practice as distinguished from legal minima. Intensity tables, representing recommended practices in various countries were also presented. Glare was discussed—attention being drawn to the method of appraisal employed in the American Factory and School Lighting Codes. The importance of adequate wiring and voltage maintenance was pointed out. Ultraviolet from both natural and artificial light was emphasized as needing future attention, but because of lack of information in many countries was not brought to definite conclusions.

Five resolutions adopted at the Cambridge meetings retained the minimum illumination values of the so-called Geneva I. C. I. Code, adopted the proposed recommended values for factories and schools, urged further study of glare appraisal, recommended further attention to electric and gas pressure, and commended adequate lighting to the attention of educators.

Three resolutions calling for analysis of glare conditions were adopted in connection with the report of the committee on fundamental research of glare. Since this committee has been discontinued, the major activity in this field is being assumed by the American Secretariat.

Automobile Headlighting

After surveying the international literature the report recommended four broad rules establishing rather liberal limits which it was hoped would be acceptable to all countries. These were based upon the shifting driving and passing

* Prepared by Mr. G. H. Stickney, Secretary-Treasurer, U. S. National Committee of the International Commission on Illumination, at the suggestion of the Editor.

beams, and were considerably more lenient as to glare than the rules of the states in this country. However, in the session at Cambridge the limits were so widened as to become unacceptable to the U. S. Secretariat and in the subsequent action of national committees most of the resolutions were rejected. The Secretariat is now with the Belgian Committee.

Lighting Application

This report is a summary of practice in sign lighting, store lighting, floodlighting and office and drafting room lighting. The 40 pages are largely devoted to compilations and tabulations from answers to questionnaires. Its purpose was principally informative, no program or conclusions being suggested. Its discussion led to a recommendation urging national committees to foster cooperation between architects and illuminating engineers. The Committee has been discontinued.

The Proceedings, which were received as this article goes to press, are in the form of a cloth-bound volume of 694 pages, illustrated with cuts and charts. The material falls in three sections, namely, recommendations passed at Cambridge, reports of discussions, secretariat reports supplemented by a few papers.

The resolutions and discussions are in French; the secretariat reports are in English, French and German. English is slightly predominant over the combined French and German in the book as a whole.

In addition to the American Secretariat reports, already referred to, there are 15 reports submitted by secretariats from other countries; *viz.:* Vocabulary (Switzerland), Definitions and Symbols (France), Heterochromatic Photometry (France), Street Lighting (Germany), Signal Glasses (Great Britain), Traffic Control Signals (Great Britain), Diffusing Materials (Germany), Photometric Test Plates (Austria), Photometric Precision (Holland), Light Flux Distribution (Belgium), Daylight Illumination (Great Britain), Cinema Lighting (Japan), Fundamental Research on Glare (France), Colorimetry (Great Britain), Lighting Education (Great Britain).

The series of Technical Committees was considerably revised at the Cambridge Session, the number being increased to 27. Of these the United States is responsible for Factory and School Lighting, Aircraft Lighting, and Lighting Education.

Work is now under way for the 1934 Meeting to be held in Germany. The U. S. National Committee will welcome appropriate papers for submission to the Sessions or to the International Illumination Congress. Authors are encouraged to communicate with the U. S. representative of the appropriate technical committee, or with the Secretary-Treasurer, G. H. Stickney, Nela Park, Cleveland, Ohio.

January 5, 1932.

International Commission on Illumination

Technical Committees to Report at 1934 Meetings in Germany

Committee	Secretariat	U. S. Representative
Factory and School Lighting	United States	H. B. Dates*
Aircraft Lighting	United States	F. C. Breckenridge*
Lighting Education	United States	C. D. Fawcett*
Vocabulary	Switzerland	E. C. Crittenden
Definitions	France	E. C. Crittenden
Standards of Light Units of Light	Bureau	E. C. Crittenden
Glare in Street Lighting	Great Britain	Ward Harrison
Gaseous Tube Photometry	Hungary	J. F. Meyer
Photometric Accuracy	Czecho-Slovakia	W. F. Little
Photometric Test Plates	Poland	W. F. Little
Physical Photometry	France	W. E. Forsythe
Colorimetry	Germany	L. A. Jones D. B. Judd
Diffusing Materials	Germany	A. A. Brainerd
Luminaire, Light Distribution	Austria	A. A. Brainerd
Street Lighting	Holland	Ward Harrison
Automobile Lighting	Belgium	C. H. Sharp
Architectural Lighting	France	A. L. Powell
Aviation, Ground Lighting	Great Britain	F. C. Breckenridge
Traffic Signals	Great Britain	M. G. Lloyd
Signal Glasses	Japan	H. P. Gage
Artificial Daylight	Sweden	K. S. Gibson
Shadows	Germany	M. Luckiesh
Mine Lighting	Great Britain	A. C. Dick
Ultraviolet	Holland	M. Luckiesh
Lighting Service	Switzerland	R. B. Brown, Jr.
Pressure Variation (Electric and Gas)	Italy	G. S. Merrill

* Director of Secretariat.

Proposed* By-Laws of The Optical Society of America, Inc.

Article I

Membership

Section 1. Classes of Membership: Membership in the society shall be regular, associate, corporation, or honorary.

Section 2. Charter Members: The members of the unincorporated association, The Optical Society of America, at the time of the incorporation of said society shall be members in their respective classifications of The Optical Society of America, Inc. The charter members of the unincorporated society shall be known as the charter members of the incorporated society.

Section 3. Eligibility: Any person who has contributed materially to the advancement of optics is eligible for regular membership.

Any person who is interested in optics is eligible for associate membership.

Any corporation desirous of encouraging the work of the society is eligible for corporation membership.

Any person who has rendered eminent service in the advancement of optics may be elected to honorary membership.

Section 4. Application for Membership: Applications for membership must state the candidate's name and qualifications for membership and must be signed by two members of the society.

Section 5. Election to Membership: All applications from individuals for membership shall be considered first as applications for associate membership and shall be acted upon as such. Applicants shall become associate members when their duly prepared applications have received the written approval of three members of the board of directors.

Applicants for corporation membership shall become corporation members when their duly prepared applications have received the written approval of three members of the board of directors.

Associate members may be transferred to regular membership at the regular annual meeting of the board of directors by a two-thirds (2/3) vote of the members of the board present.

Honorary members may be elected at the regular annual meeting of the board of directors by the unanimous vote of the entire board. In case any members of the board are not in attendance their ballots must be obtained by the secretary. The number of honorary members shall at no time exceed five (5).

Section 6. Duties and Privileges: Regular members shall have the right to vote, hold office, attend meetings, and receive the journal of the society and such other publications as the board of directors may direct.

Associate members shall have the same privileges as regular members except that they may not vote or hold office.

Corporation members shall receive the journal of the society and such other publications as the board of directors may direct. Their representatives may attend all meetings of the society.

Honorary members shall have all of the privileges of regular members.

Section 7. Termination of Membership: Membership in the society may be suspended or terminated by vote of the board of directors. Failure to pay dues for one (1) year shall be deemed sufficient cause for suspension or termination of membership.

Section 8. Dues: The dues for regular members shall be seven dollars and fifty cents ($7.50) per annum.

The dues for associate members shall be five dollars ($5.00) per annum.

The dues for corporation members shall be fifty dollars ($50.00) per annum.

The payment of one hundred dollars ($100.00) in one sum shall exempt any regular or associate

* Prepared by a special committee of the Executive Council and approved by the Board of Directors at its meeting in New York, February 23, 1933, for submission to a vote of the Society, pursuant to the resolution for the incorporation of the Society approved by ballot May 24, 1932. Ballots on the adoption of these proposed by-laws will be mailed to all regular and honorary members of the Society.

member from the subsequent payment of dues for the remainder of his life.

Section 9. Patrons: The payment, within any one year, of one thousand dollars ($1000.00) or more toward the expenses of the society by any corporation or individual shall entitle such corporation or individual to the rank of patron of the society, for a period of ten years in the case of a corporation, and for life in the case of an individual.

Section 10. Ownership of Corporation Property: The corporation shall not be operated for profit and its entire properties, assets, and facilities shall be devoted to the purposes for which it is organized as set forth in its certificate of incorporation as the same may be from time to time amended. No member shall have any right to or any share or interest in any of the property or assets of the corporation.

Article II

Meetings of Members

Section 1. Annual Meeting of the Corporation: During October of each year at a time and place to be fixed by the board of directors, there shall be held the annual meeting of the members of the corporation for the election of directors and officers (if not previously elected by mailed ballot as hereinafter provided), and for the rendering to the membership of the annual report of the directors as required by law, and for the transaction of such other business as may properly come before the meeting.

At each annual meeting the directors shall present a report verified by the President and Treasurer or by a majority of the directors, showing the whole amount of real and personal property owned by the corporation, where located and where and how invested, the amount and nature of the property acquired during the year immediately preceding the date of the report, and the manner of the acquisition; the amount applied, appropriated or expended during the year immediately preceding such date, and the purposes, objects, or persons to or for which such applications, appropriations or expenditures have been made; and the names and places of residence of the persons who have been admitted to membership in the corporation during such year, which report shall be filed with the records of the corporation and an abstract thereof entered in the minutes of the annual meeting.

Section 2. Notice of Annual Meeting: Notice of the annual meeting of members shall be given by mailing, not less than ten (10) days nor more than forty (40) days before the meeting, a copy of the notice of such meeting to every member of the corporation directed to him at his address as it appears upon the records of the corporation.

Section 3. Special Meetings: Special meetings of the members, except as otherwise provided by law or by these bylaws, may be called at any time by the board of directors or by the President, and shall be called by the President or by the Secretary at the request in writing of a majority of the board of directors. Such request shall state the purpose or purposes of the proposed meeting.

Section 4. Notice of Special Meetings: Notice of each special meeting of the members shall be given by mailing, not less than ten (10) nor more than forty (40) days before the meeting, a copy of the notice of such meeting, stating the purpose or purposes for which the same is called, to each member directed to him at his address as it appears on the records of the corporation.

Section 5. Quorum: At any meeting of the members of the corporation a quorum shall consist of not less than twenty (20) voting members.

Section 6. Qualifications of Voters: Upon any question presented for vote to the membership, whether presented by mail or at a meeting of the members, each member entitled to vote pursuant to the provision of Section 6 of Article I shall be entitled to one (1) vote.

Section 7. Voting: Upon any question with respect to which a vote of the membership shall be required or deemed advisable, the board of directors may determine whether such vote shall be taken by mail or by ballot at the next meeting of the membership. In case the directors shall determine to take such vote by mail, either upon any question of administration or policy or upon the election of officers, directors or others, forms for the casting of such vote or for the casting of a ballot for the election of any such officers, directors, or others, shall be forwarded to the entire membership entitled to vote thereon at least thirty (30) days prior to the date upon which the count of such votes or ballots shall be made by

the directors (the date of which count shall be incorporated in the advice sent to the respective members) and the result of such vote or ballot shall be determined by the directors upon the date fixed for such purpose and shall be valid, binding and of full force and effect precisely as if such vote had been taken in open meeting of the membership regularly called and duly held, provided always, that in order to render valid such vote by mail, the number of votes cast shall be at least equal to the number of voting members required to constitute a quorum at any regular or special meeting of the membership.

Article III

Officers and Directors

Section 1. Officers Enumerated: The officers of the society shall be a President, a Vice-President, a Secretary, a Treasurer, a Junior Past-President, and an Editor of Publications.

Section 2. Directors Enumerated: The directors shall consist of the six (6) officers mentioned in Section 1, all of whom shall be, ex-officio, members of the board of directors, and five (5) directors-at-large.

Section 3. Eligibility and Election: Nine (9) directors and officers shall be elected by the voting members from among the regular and honorary members of the society. These directors shall consist of five (5) directors-at-large and the following officers of the society who shall be, ex-officio, members of the board of directors, to wit: president, vice-president, secretary, and treasurer.

At the expiration of his term of office the president becomes the junior past-president, one of the officers of the society, and, ex-officio, a member of the board of directors.

The editor of publications shall be elected by the above enumerated board of directors at an annual meeting of the board and shall upon such election become a voting member of such board.

Section 4. Terms of Office: The president and vice-president shall be elected for terms of two (2) years.

The secretary and the treasurer shall be elected for terms of four (4) years.

No officer elected by the membership shall be eligible for re-election except when such eligibility is established by special action of the board of directors. This shall require an affirmative vote of three-fourths (3/4) of the entire board.

The junior past-president shall serve until such time as his successor qualifies for the office by retiring from the office of president.

The editor of publications shall be elected for a term of four (4) years.

Members at large of the board of directors shall be elected for terms of four (4) years, except that at the first election following the formation of this corporation two (2) of these directors-at-large shall be elected for terms of two (2) years. At the expiration of the terms of these two directors-at-large their successors shall then be elected for terms of four (4) years as provided in the first sentence of this paragraph.

No member at large of the board of directors shall be eligible for re-election.

The term "re-election" as used in these by-laws shall be construed to mean only the election of an individual to succeed himself.

Section 5. Time of Election and Assumption of Duties: Election by the members of officers and members at large of the board of directors shall take place at an annual meeting of members in October, or by mailed ballot as provided in the following section.

The officers and directors elected shall assume their duties at the close of such annual meeting, or, if the vote is taken by mailed ballot, upon the date set as provided in Section 7 of Article II for the counting of such ballots.

Section 6. Mode of Election: Elections shall be by ballot cast by mail as provided in Section 7 of Article II unless the board of directors shall, prior to the holding of any annual meeting of the membership, determine to hold such election at such annual meeting, in which case the members entitled to vote shall be notified of such determination. Where more than two candidates are nominated for any one office the voting shall be by preferential ballot. Nominations shall be made by a nominating committee appointed by the President and approved by the board of directors. This committee shall consist of five (5) regular members of the corporation, at least one (1) of whom shall be a past-president.

Notices of the nominations made by the nominating committee shall be sent to all regular members at least thirty (30) days before the date

on which the ballots are forwarded to the members. Additional nominations may be made by request of ten (10) members qualified to vote provided they are forwarded to the Secretary within twenty (20) days after notices of the nominations are sent out.

Section 7. Vacancies: In the event of a vacancy occurring among the officers or the directors-at-large, the remaining directors, by an affirmative vote of a majority thereof, may fill such vacancy until the next annual meeting of the corporation.

Section 8. Organization of the Board of Directors: The President of the society shall be the chairman of the board of directors.

The Secretary of the society shall be the secretary of the board of directors. He shall keep complete and precise records of the business transacted by the board of directors and shall send copies of the minutes to each member of the board and shall file copies of the minutes in a permanent record book provided for the purpose.

Section 9. Meetings of the Directors: The annual meeting of the board of directors shall be held in October. Meetings of the directors may be held at such other times as the chairman of the board may appoint. The directors may adopt rules and regulations governing their procedure, the notices to be given of meetings, the times and places of holding of regular meetings, and other matters with respect to the conduct of their business. The vote of directors upon any proposition, except as otherwise provided by these by-laws, may be obtained by mail during an interim between meetings.

Section 10. Quorum: At any meeting of the board of directors a majority of the entire membership of the board shall constitute a quorum and, except as otherwise provided by these by-laws, a majority of such a quorum shall decide any question that may come before the meeting.

Section 11. Duties of Officers: The duties of the President, Vice-President, Secretary, and Treasurer of the society shall be the usual ones performed by such officers.

The Treasurer shall be chargeable with the responsibility for the general funds of the corporation and for such special funds as may be from time to time placed in his custody or control by order of the board of directors, and he shall pay the bills of the corporation which have been approved by the board of directors either through adoption of an annual budget or by special action.

The custody of other special funds may be vested by the board of directors in agents other than the Treasurer.

The Treasurer and each other officer or agent having custody or control of any funds shall report periodically and at least once each year to the board of directors with respect to the management and disposition of the fund or funds with which he is chargeable, and the board of directors shall in turn incorporate such reports in their annual report to the members.

The Editor of Publications shall have general charge under the supervision of the board of directors, of the publications of the society as set forth in Section 1 of Article V.

Section 12. Bonding: The Treasurer and each other officer or agent having custody or control of any funds of the corporation shall be bonded for an amount to be fixed by the board of directors.

Section 13. Prohibitions on Officers: No director or other officer of the society shall receive, directly or indirectly, any salary, compensation or emolument from the corporation, either as such officer or director or in any other capacity, unless authorized by the by-laws of the society, or by the affirmative vote of two-thirds (2/3) of all the directors.

No director or other officer of the society shall be interested, directly or indirectly, in any contract relating to the operations conducted by the society, nor in any contract for furnishing supplies thereto, unless authorized by the by-laws of the society or by the affirmative vote of two-thirds (2/3) of the directors.

Article IV

Committees and Delegates

Section 1. Committees: The President may appoint, subject to the approval of the board of directors, such committees as may further the objects of the society, and such committees shall have such duties and responsibilities as shall be delegated to them by the President and the board of directors, but shall be subject at all times to the direction and control of the board of directors.

The life of each such committee shall terminate with the expiration of the term of office of the President by whom it was appointed.

Section 2. Representatives and Delegates: The President shall submit to the board of directors nominations for representatives and delegates to other organizations. Representatives and delegates shall be elected by the board of directors and for such terms as their respective offices may require.

Article V

Publications and Endowments

Section 1. Publications: The society shall publish a journal devoted to the advancement of optics and may publish such other scientific publications as may be deemed advisable by the board of directors from time to time. In addition to the Editor of Publications, who shall be a member of the board of directors as hereinabove provided, the board of directors may appoint six or more associate editors whose terms of office shall be six (6) years, one-third (1/3) of them to be appointed biennially, but such appointments to be at all times subject to revocation by the board of directors. Every regular, associate, corporation, and honorary member of the society shall be entitled to receive the journal of the society.

Section 2. Endowments: The corporation may accept endowments for medals, scholarships, or for other purposes, and such endowments shall be maintained in accordance with the directions of the board of directors and the wishes of the donors.

Article VI

Finances

Section 1. Finances: The respective funds of the corporation shall be deposited with such bank or banks, trust company or trust companies as the board of directors may from time to time designate, and shall be subject to withdrawal by such officers or agents as may from time to time be designated by the board of directors.

Article VII

Corporate Seal

Section 1. Form of Seal: The seal of the corporation shall be circular in form with the words "Optical Society of America, Inc., New York" in the outer circle and "1932" together with the official emblem of the society within the inner circle. Such seal as is impressed on the margin hereof is hereby adopted as the corporate seal of the corporation.

Article VIII

Amendments

Section 1. Amendments by Directors: These by-laws may be amended, altered, or repealed in whole or in part by the affirmative vote of the majority of the entire board of directors expressed in writing or cast at any regular or special meeting of the board with or without mention thereof in the notice of the meeting at which the vote is taken. If, however, any such amendment is adopted at a meeting without mention thereof in the notice of such meeting, a copy of such amendment shall be mailed immediately after the meeting to each director not present at the meeting.

Section 2. Amendments by Members: These by-laws may be amended, altered, or repealed in whole or in part by the affirmative vote of a majority of the regular members of the society in good standing expressed in writing as provided in Section 7 of Article II or cast at any annual meeting of the members or at any special meeting of the members where such proposed action has been incorporated in the notice of the meeting. Amendments by the members may be made notwithstanding any previous action of the board of directors.